Recent developments in Nuclear Medicine imaging technologies

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Presentation Overview

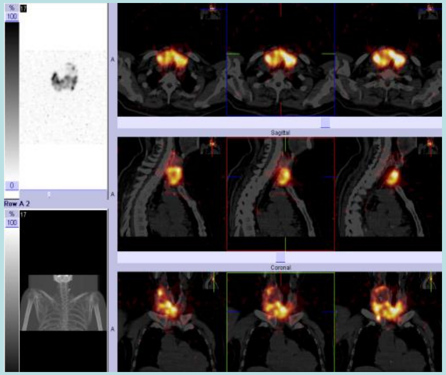
- Basic principle of NM diagnostic process!

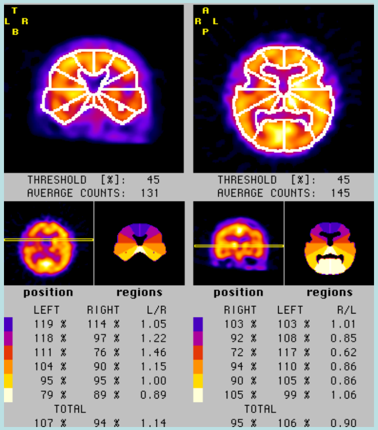
- SPECT:
  - SPECT/CT
  - Development in SPECT detection instrumentation
  - New approaches in SPECT:
    - solid state detector
    - CZT
- PET scanners:
  - PET/CT
  - Development in PET detector and TOF technology
  - Improvements to processing software

- Technological challenges faced by NM hybrid imaging

How are the images made ?

- Patient receives radioactive tracer tagged to a pharmaceutical (radiopharmaceutical).
- Radio pharmaceutical travels to organ of interest.
- Patient imaged with a Gamma Camera



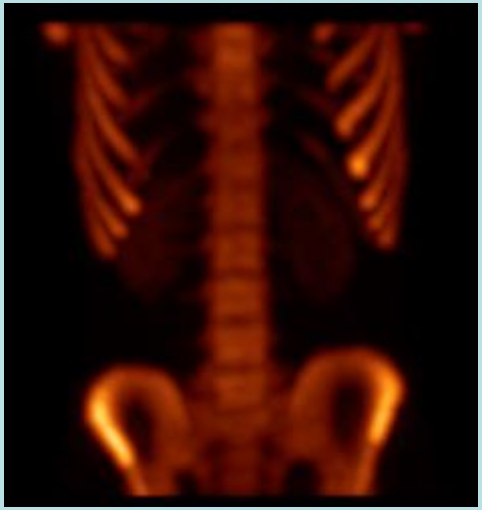


What Makes Nuclear Unique?

- **Nuclear Medicine is the only imaging modality based purely on physiology**
  - **Images provide information on organ function**

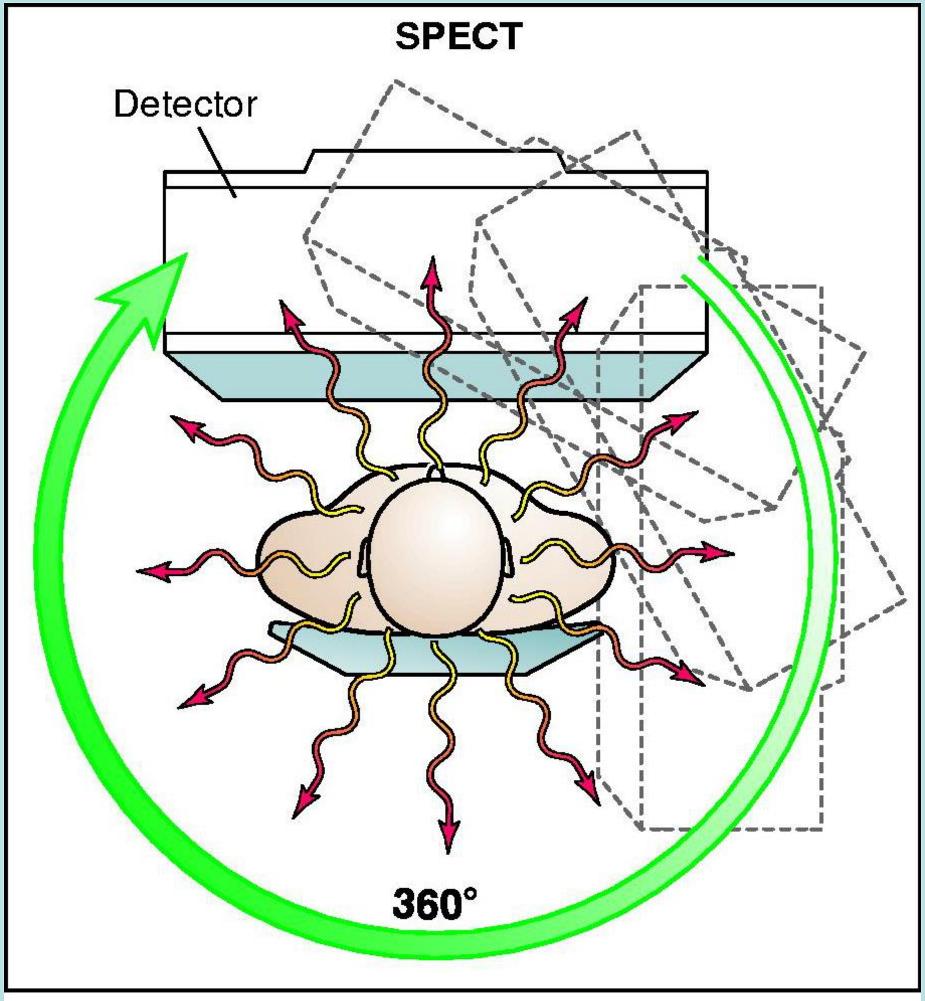
Identify normal vs abnormal function -
Provide quantitative measurements of function

- Detect heart disease and cardiac function
- Diagnose, stage, and monitor cancer therapy and progression
- Blood flow / function of various organs
- Infections, blood clots, or arthritis
- Fractures
- Internal bleeding



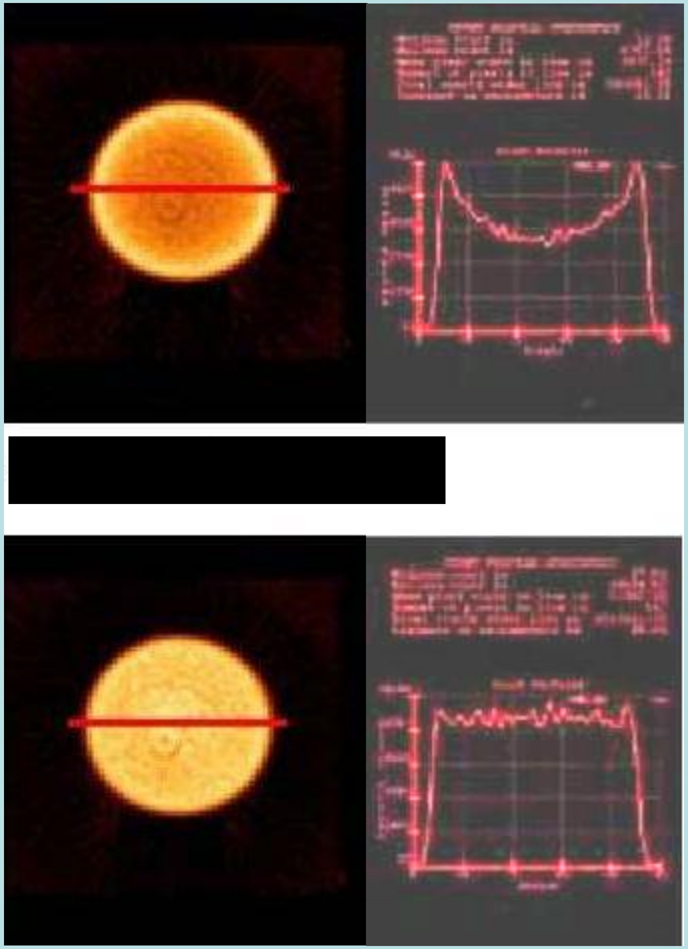
SPECT basics

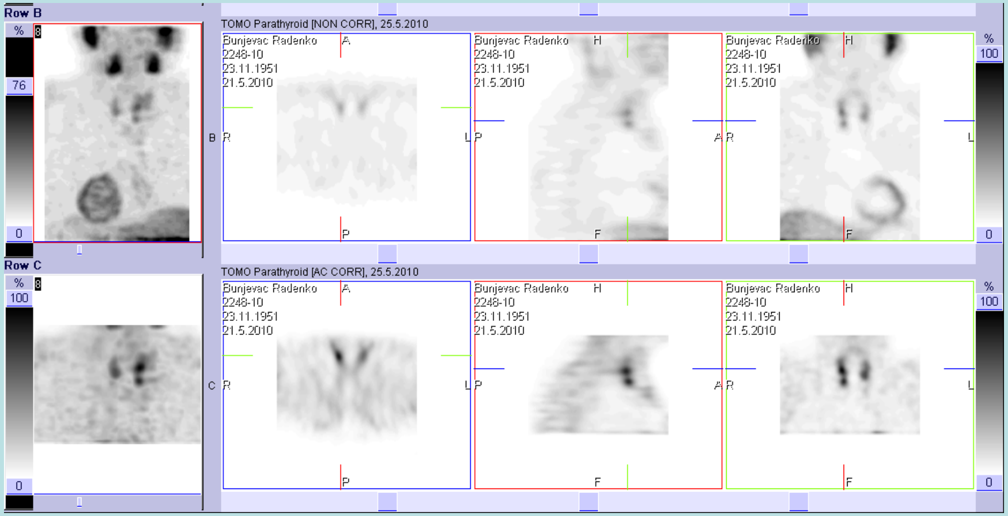
- **Collect data over at least 180 degrees.**
- **Reconstruction of transaxial slices.**
- **Filtered back projection**
- **Iterative reconstruction**



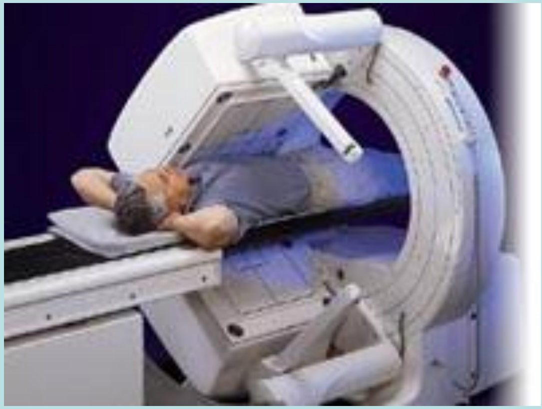
Attenuation

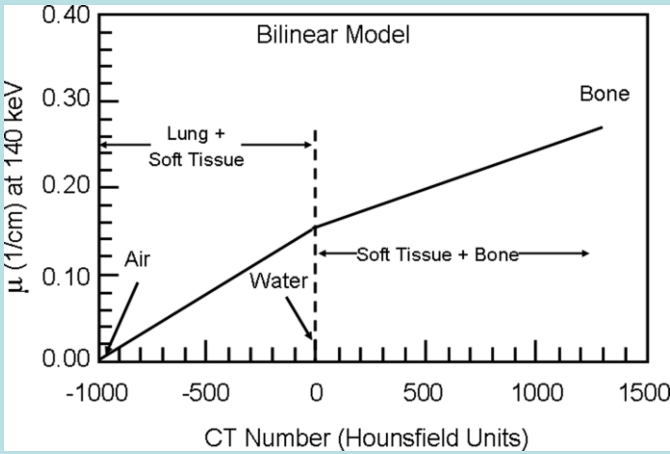
- **Reduced counts from deep in the body because of photon attenuation.**





Attenuation Correction





- **Applying a uniform attenuation map**

  Based on a “theoretical” linear attenuation coefficient.

- **Applying a non-uniform attenuation map acquired from a <u>transmission scan</u>**

  Gamma ray based attenuation correction (Scanning line sources, Gd-153…)

  X-Ray based attenuation correction (SPECT/CT and PET/CT)

Cardiology

corected

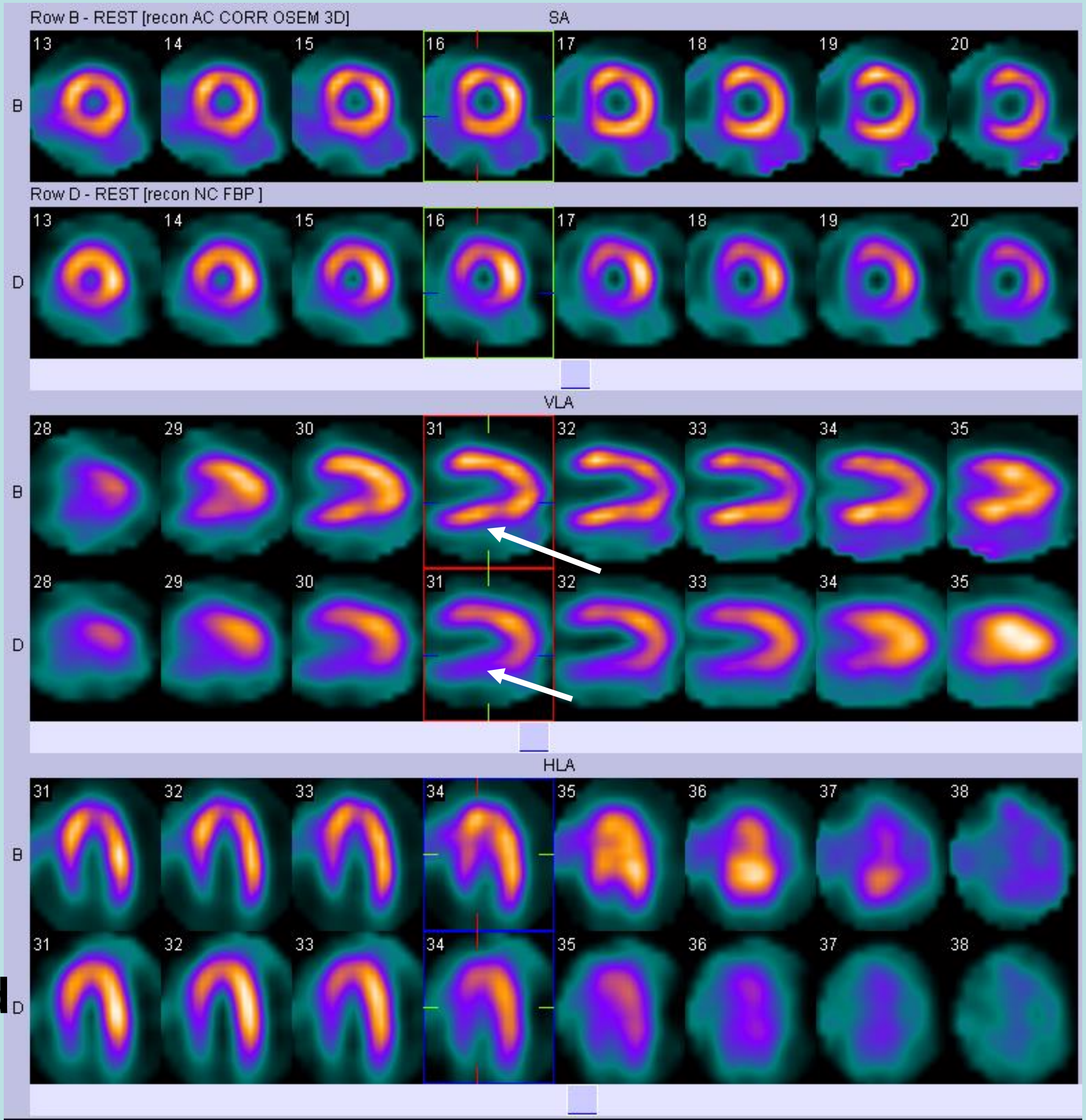
non corected

corected

non corected

corected

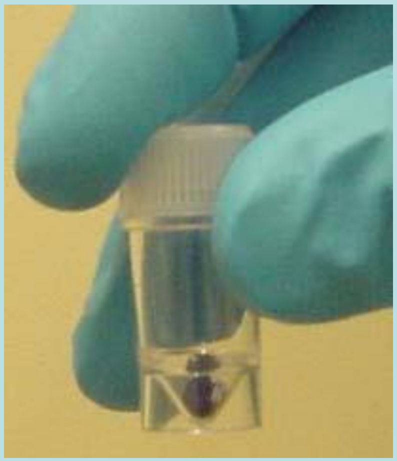
non corected

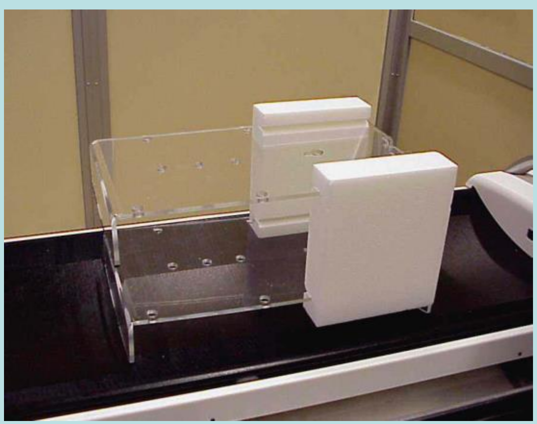


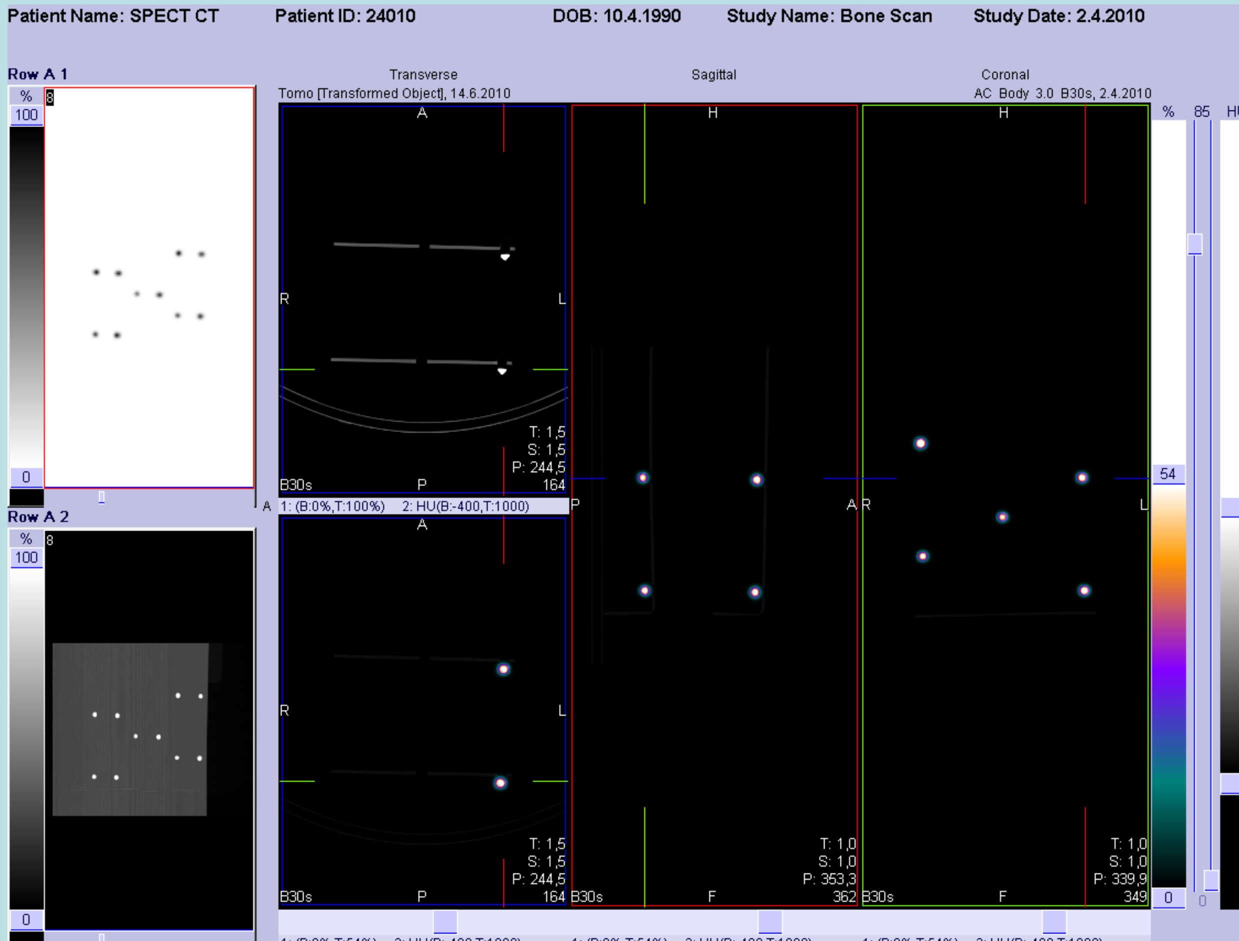
Advantages of SPECT/CT

- Improved attenuation correction, resulting from the more accurate and precise attenuation map with CT.
- Add value to SPECT studies with superior quantification of radiotracer uptake.
- Ability to perform complementary diagnostic studies in the same setting
    - making both of these studies more efficient and convenient for the patient.

QC






Patient Name: SPECT CT
Patient ID: 24010
DOB: 10.4.1990
Study Name: Bone Scan
Study Date: 2.4.2010
Row A 1
Transverse
Sagittal
Coronal
Tomo [Transformed Object], 14.6.2010
AC Body 3.0 B30s, 2.4.2010
%
100
0
A
R
L
P
B30s
T: 1,5
S: 1,5
P: 244,5
164
1: (B:0%,T:100%) 2: HU(B:-400,T:1000)
Row A 2
H
F
T: 1,0
S: 1,0
P: 353,3
362
P: 339,9
349
85
HU
54
1: (B:0%,T:54%) 2: HU(B:-400,T:1000)

Development in SPECT; Scintillators

- **The most commonly used detector material for the SPECT is the NaI(Tl),**
- **CsI(Tl), CsI(Na) and $LaBr_3$ are starting to be used.**

Scintillator	Atomic number Z effective	Density p (g/cm3)	Decay time (ns)	Wavelength (nm)	Relative light output (% of NaI(Tl))	Remarks
NaI (Tl)	50	3,67	200	415	**100**	
CsI (Tl)	54	4,5	1.000	550	45 (118*)	Long wavelength; Cardius.
CsI (Na)	54	4,51	630	420	85	Used in LinoView, s animal
LaBr3:Ce	47	5,3	25	360	160	Used in s animal SPECT

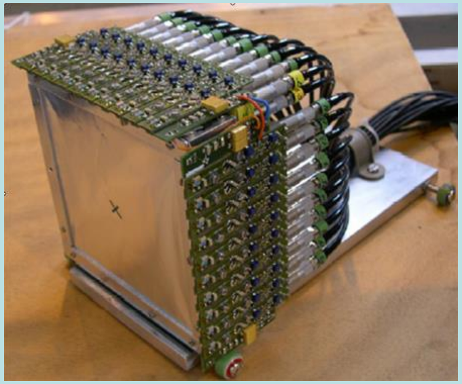
Development in SPECT;
Photon Transducers

Conventional PMT

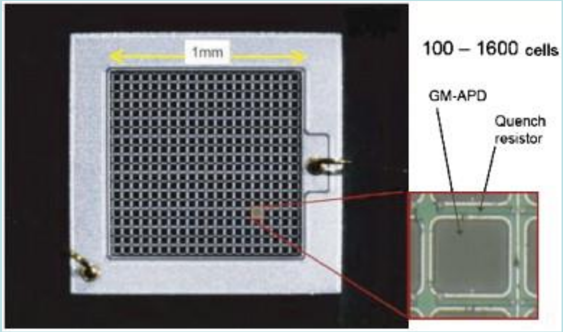
Conventional PMTs

Other Photodetectors:

- **the position sensitive PMT(PSPMT),**
- **avalanche photodiode (APD),**
- **silicon photomultiplier**



Avalanche photodiode



Silicon photomultiplier

A pair of Hamamatsu H8500 square face (52 mm x 52 mm) Position Sensitive Photomultiplier Tubes (PSPMTs)

Development in SPECT;
Semiconductors Detectors

- **Cadmium telluride (CdTe) and cadmium zinc telluride (CdZnTe); promising materials for radiation detectors:**

- **with good energy resolution,**
- **better sensitivity,**
- **better scatter rejection,**
- **and room temperature operation.**

- **A semiconductor camera also provides improved image contrast due to its better energy resolution compared to a sodium iodide crystal.**

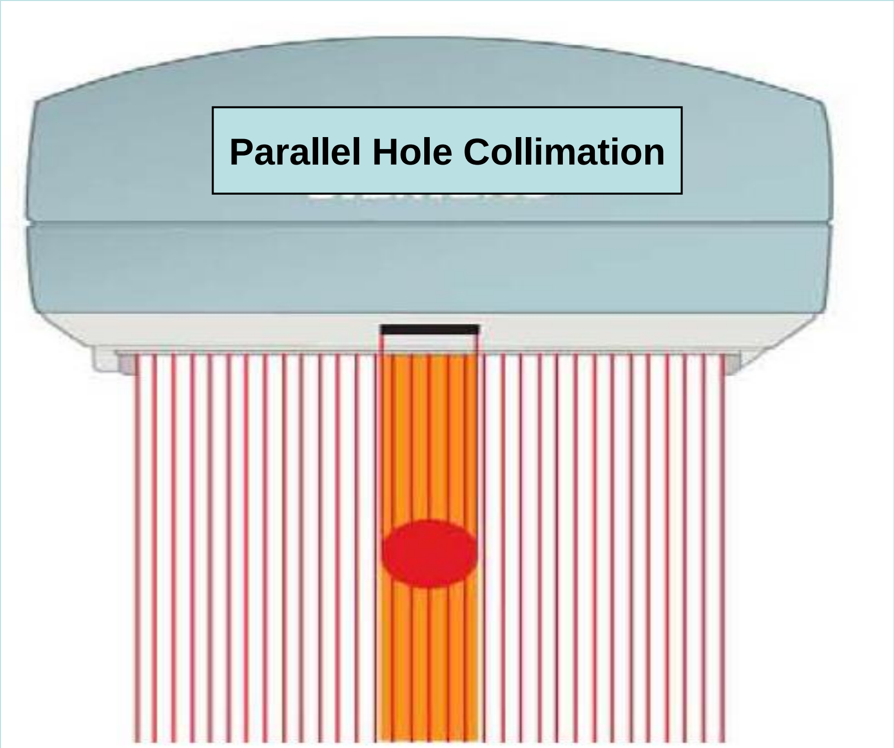
New Approaches in SPECT

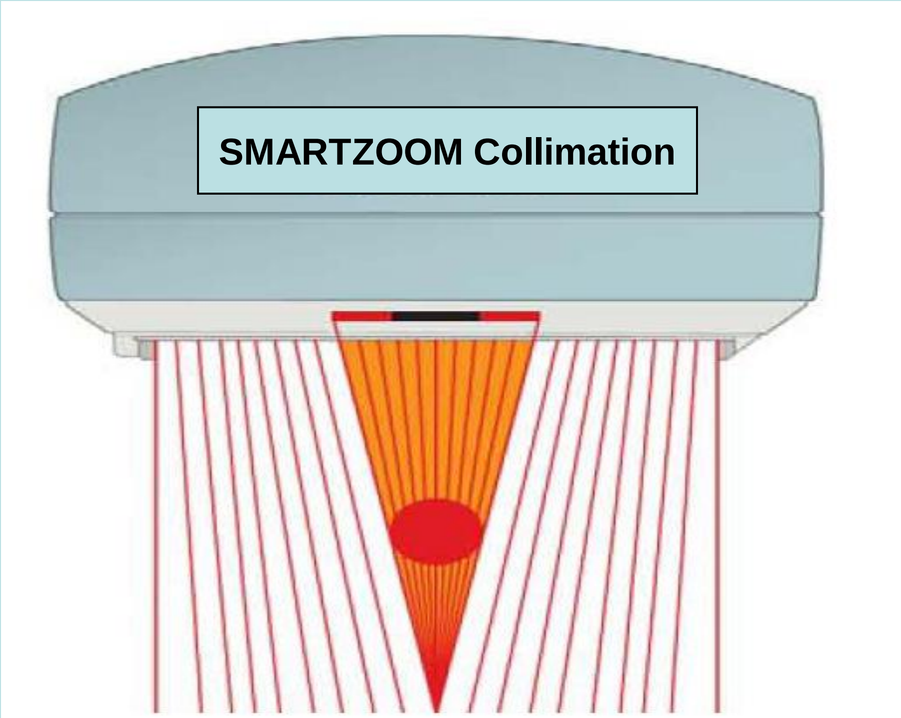
Recently a number of new imaging systems have been introduced, that

were designed specifically for cardiac imaging applications:

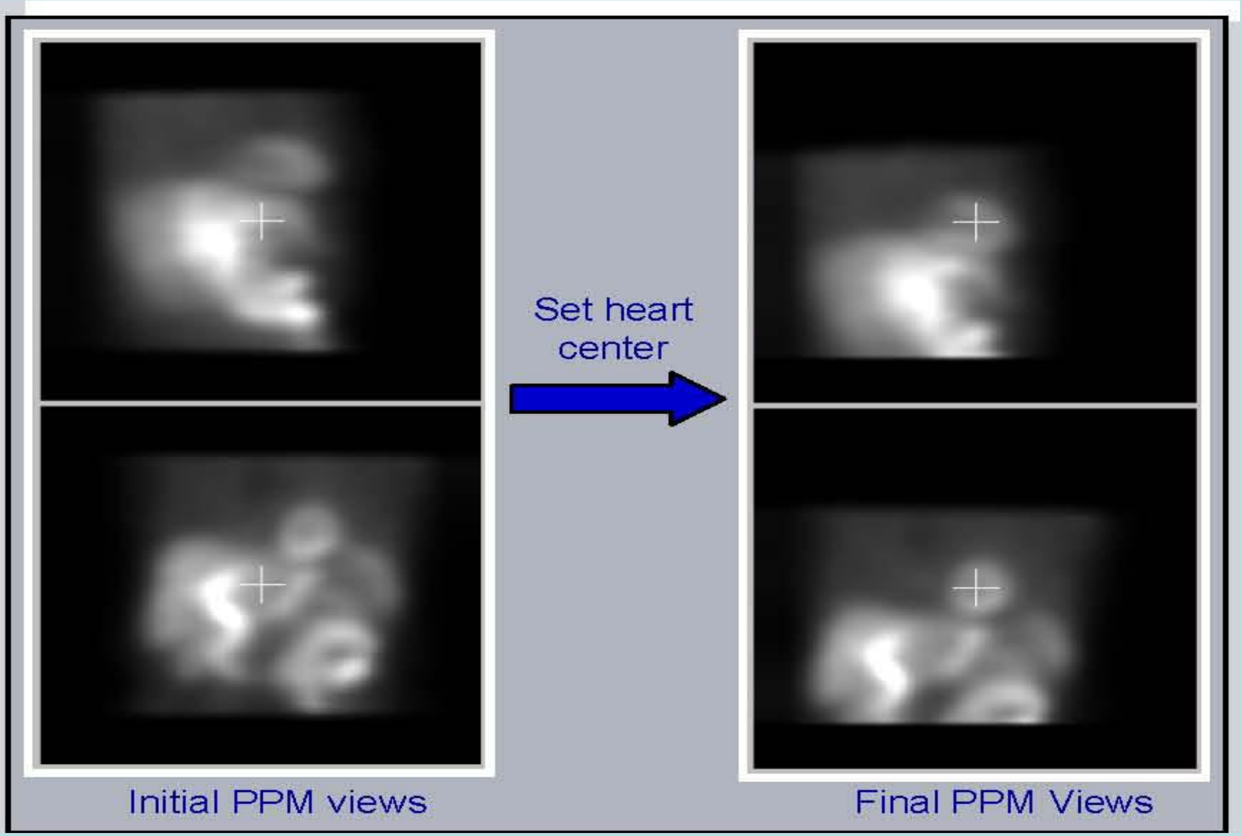
- **Cardius XCT™, manufactured by Digirad, Inc. Poway, CA**
- **CardiArc, Inc. Lubbock, TX**
- **D-SPECT™ Manufactured by Spectrum Dynamics, Haifa, Israel**
- **Alcyone™ ; GE Healthcare using Alcyone detector**

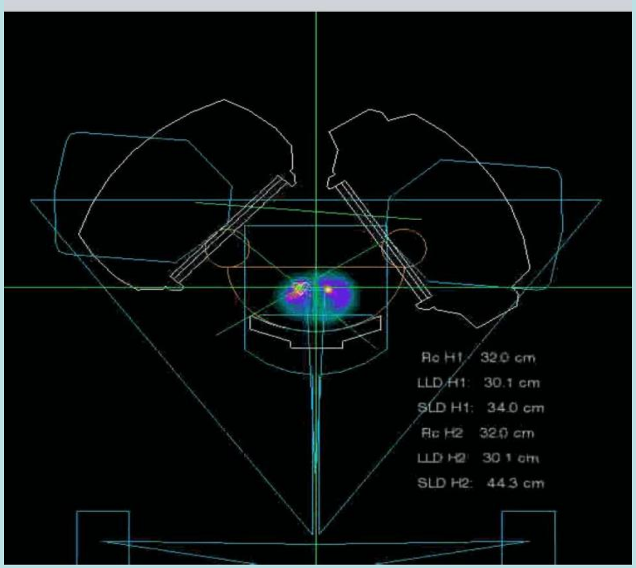
IQ-SPECT Collimation



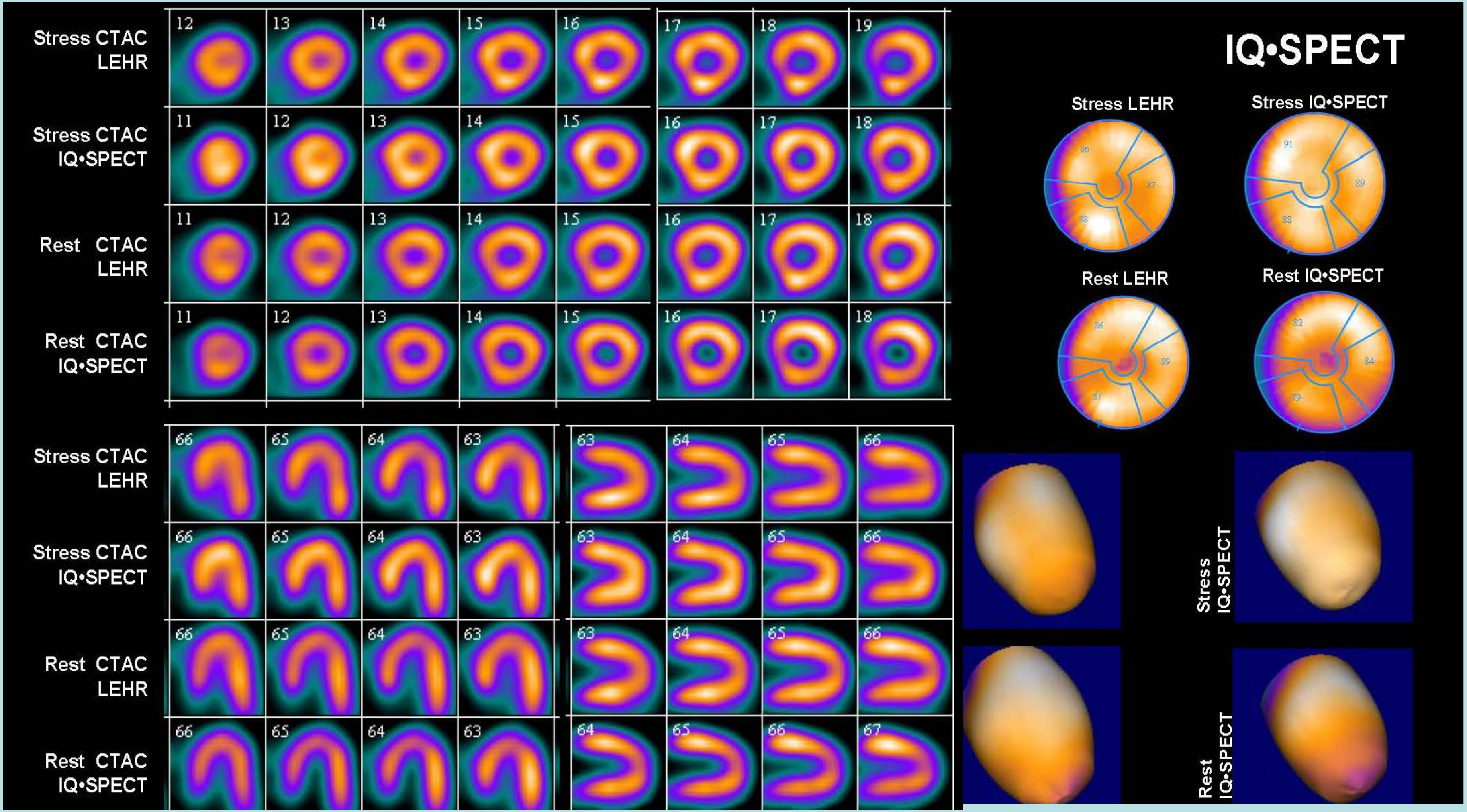


Smart Zoom Collimator: Acqusition

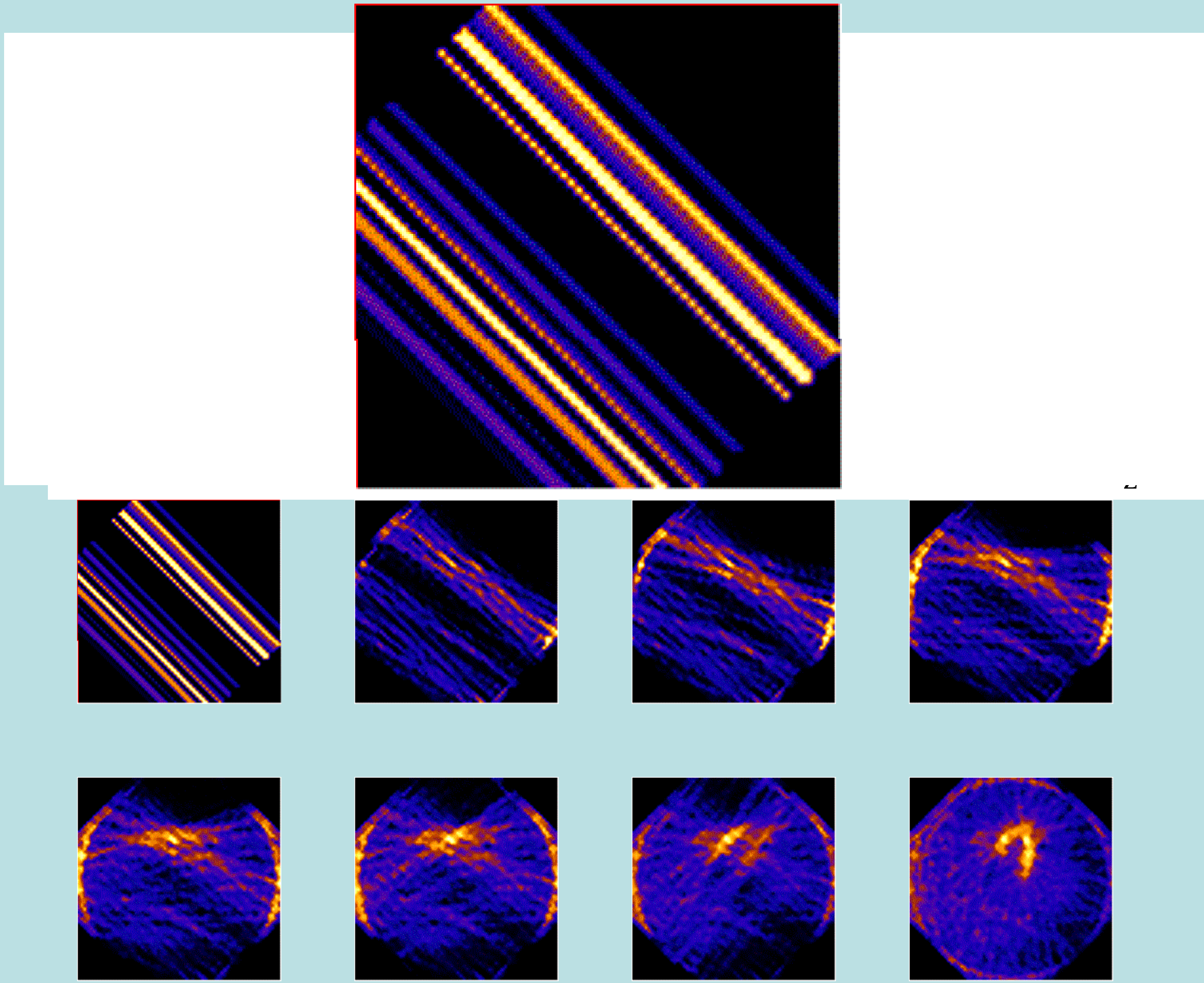




Processing

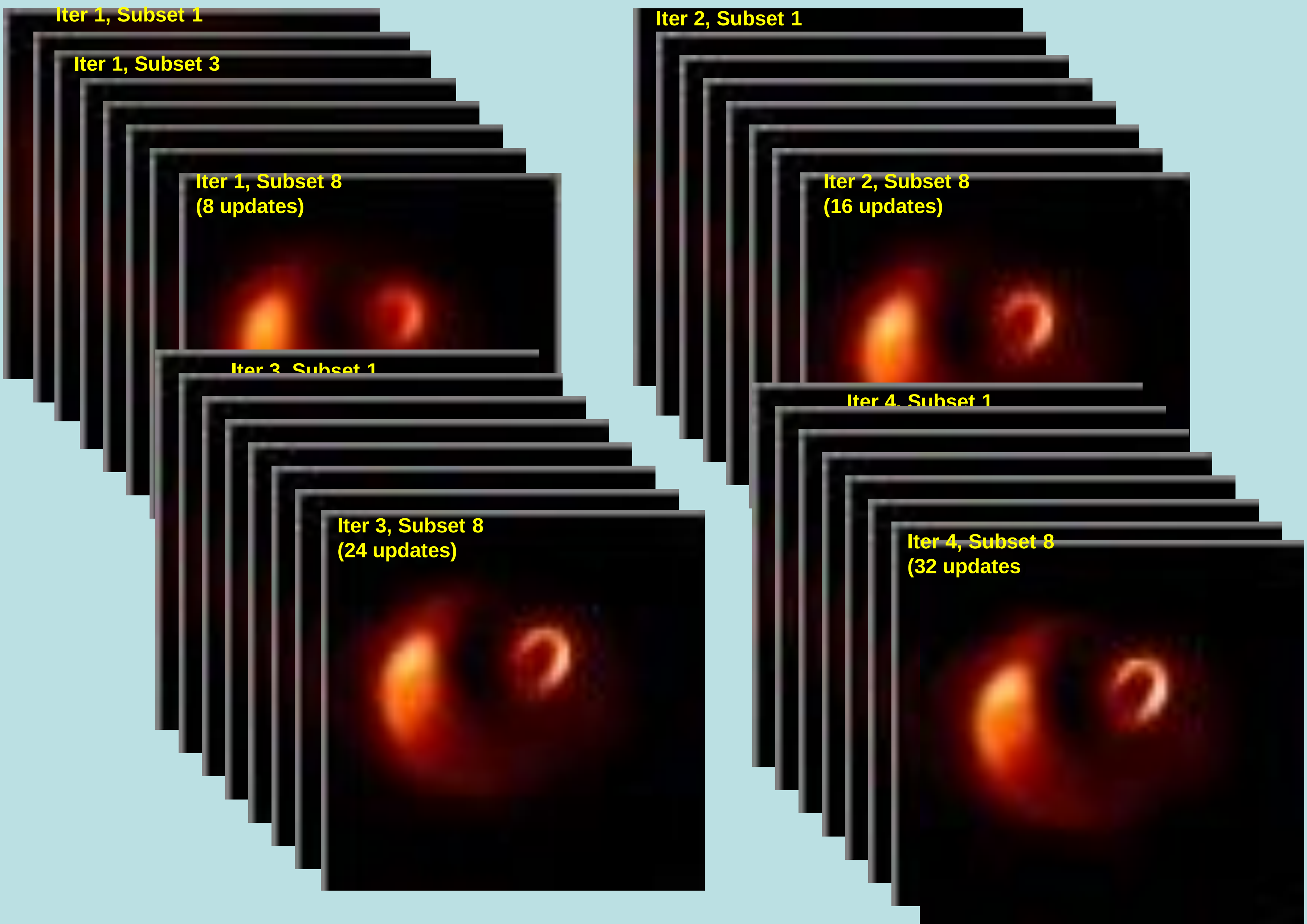

Stress CTAC LEHR
Stress CTAC IQ•SPECT
Rest CTAC LEHR
Rest CTAC IQ•SPECT
IQ•SPECT
Stress LEHR
Stress IQ•SPECT
Rest LEHR
Rest IQ•SPECT
Stress CTAC LEHR
Stress CTAC IQ•SPECT
Rest CTAC LEHR
Rest CTAC IQ•SPECT
Stress IQ•SPECT
Rest IQ•SPECT

Tomographic reconstruction



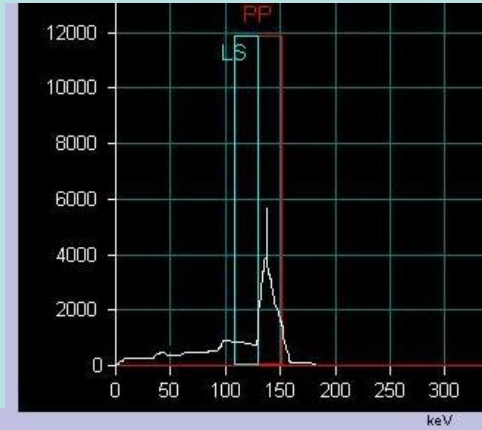
Cardiac Patient Convergence

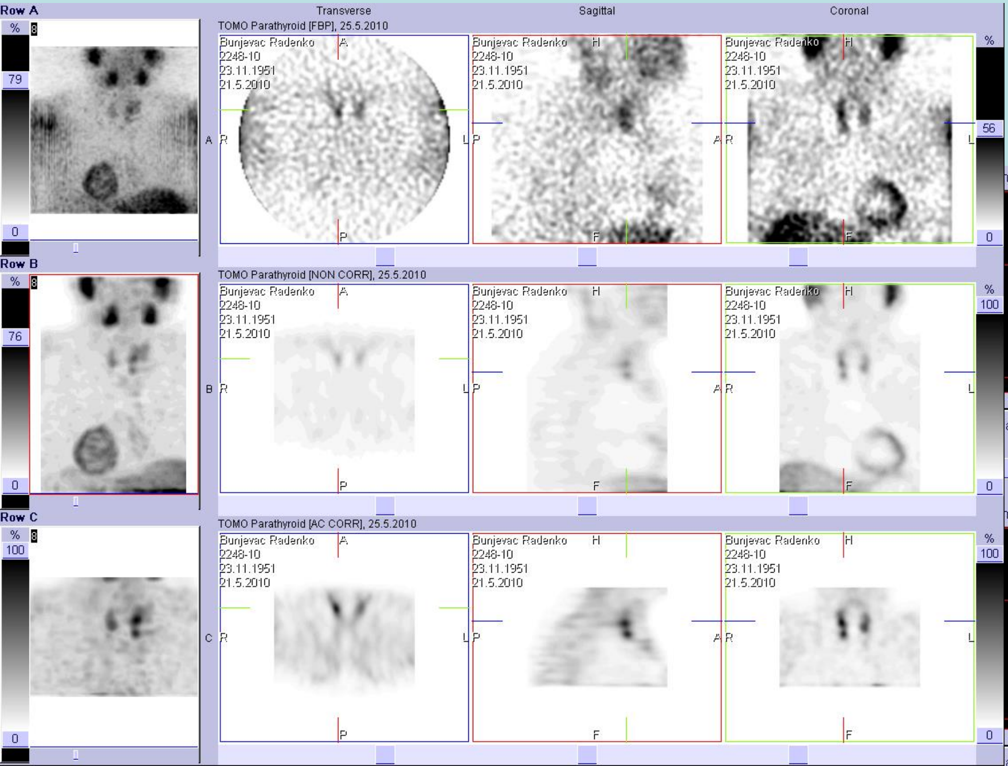
(Iter=4, sub= 8, Hann=1.0)

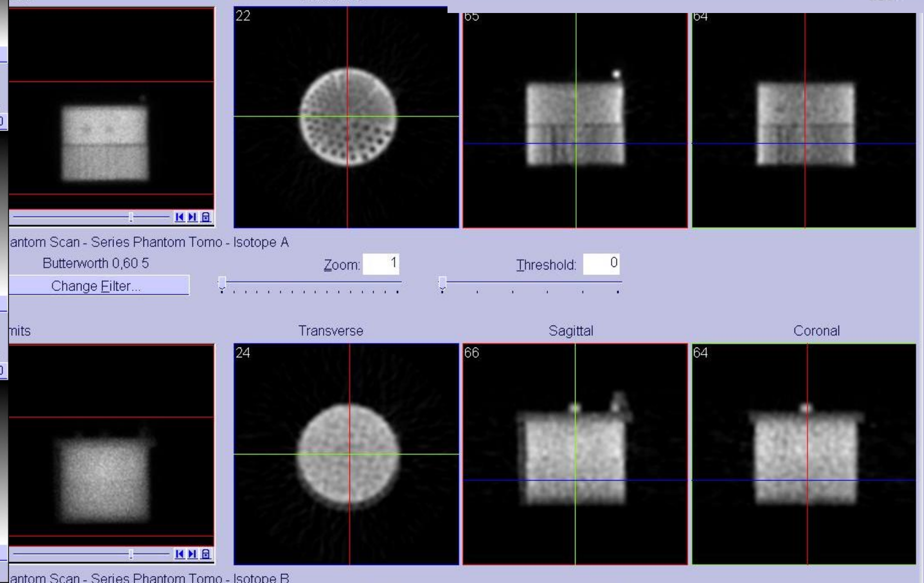


Development in SPECT; processing software

- New commercial products for improving the quality of SPECT:
  - Astonish from Philips,
  - Evolution from GE Healthcare,
  - Flash 3D from Siemens,
  - Wide Beam Reconstruction from UltraSPECT.

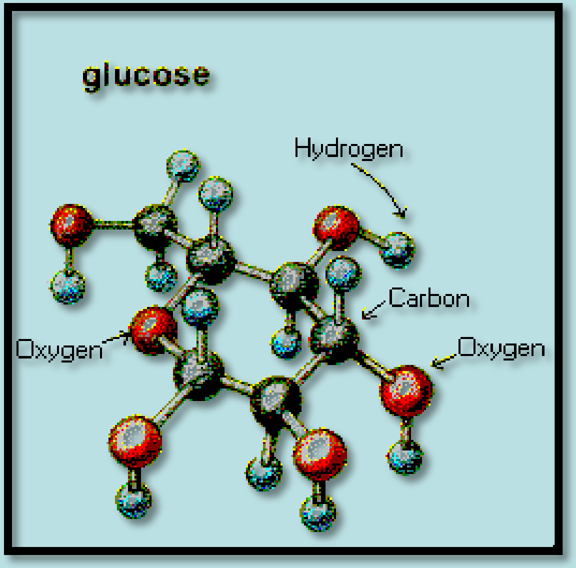


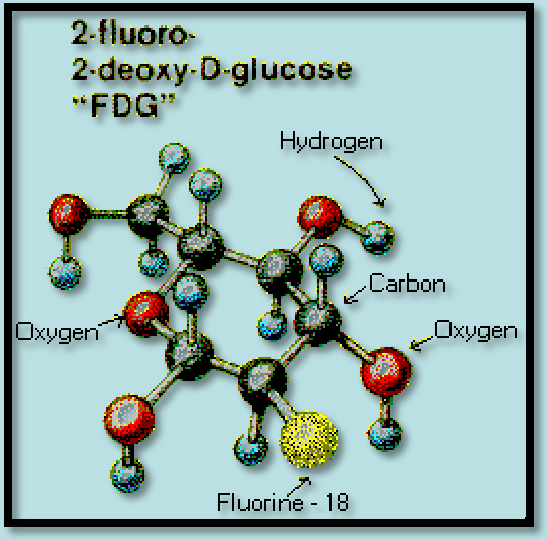




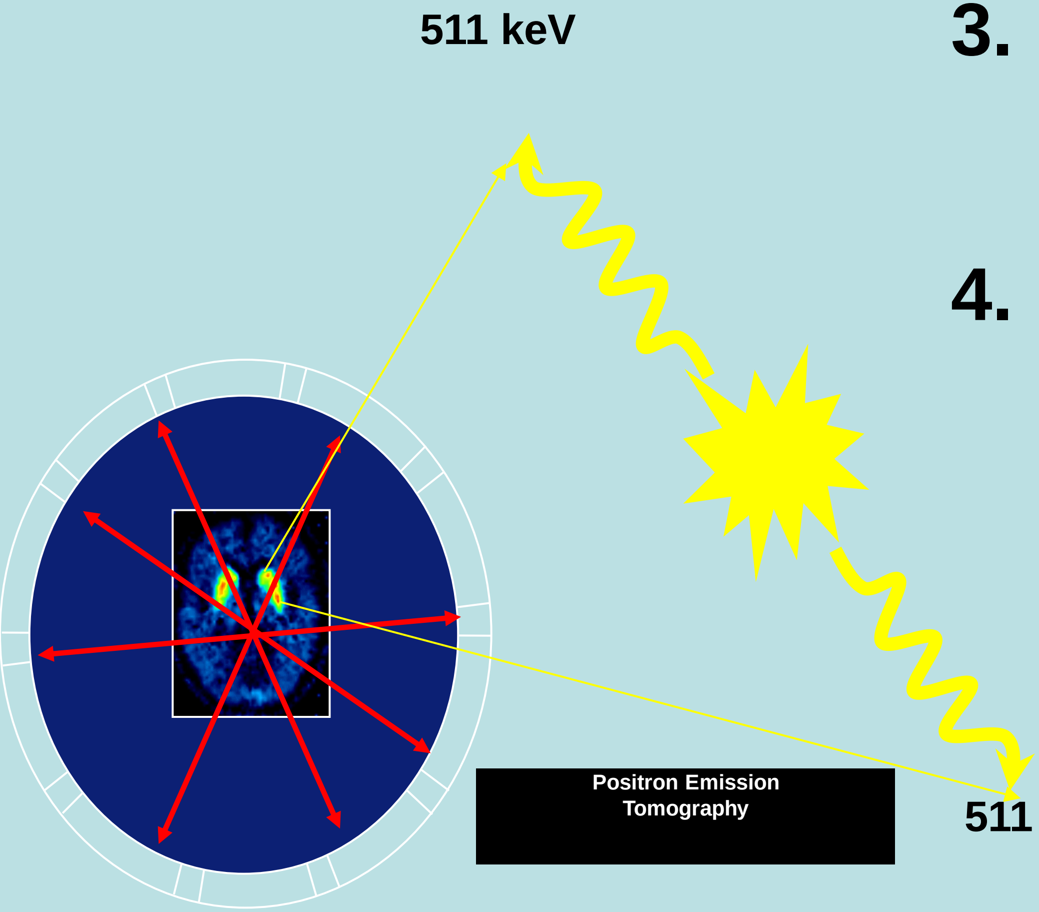
How is a PET image formed?

1. Patient is injected with radio-pharmaceutical (usually FDG).
2. Wait for uptake (usually ~60 minutes)
   - FDG taken up by cells that metabolize glucose.



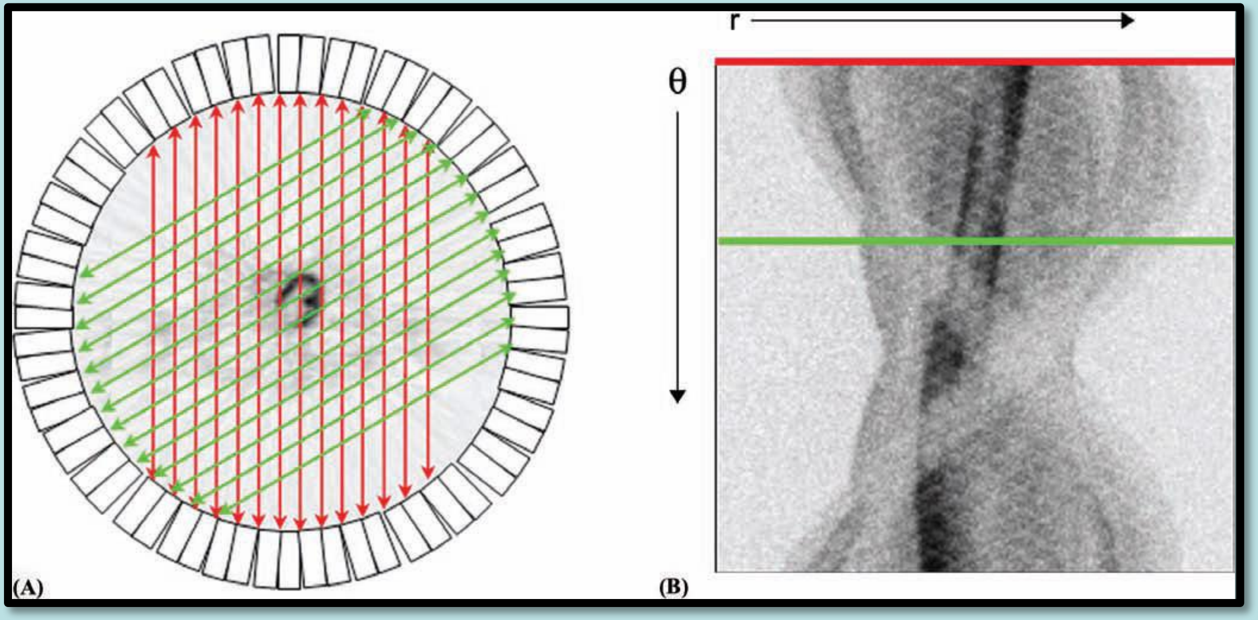


How is a PET image formed?



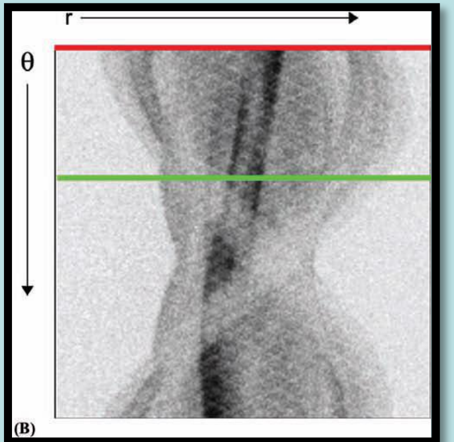
3. Radioactive isotope emits positrons
   - Collide and "Anihilate" with an electron
   - Two 511 keV photons emitted 180 degrees apart
4. Millions of Coincidence pairs recorded to form an image

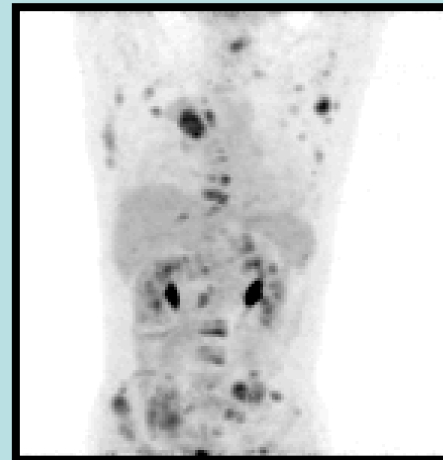
How is a PET image formed?



- **Full ring PET scanners simultaneously measure multiple projections at different angles, which are typically stored in sinograms.**

How is a PET image formed?



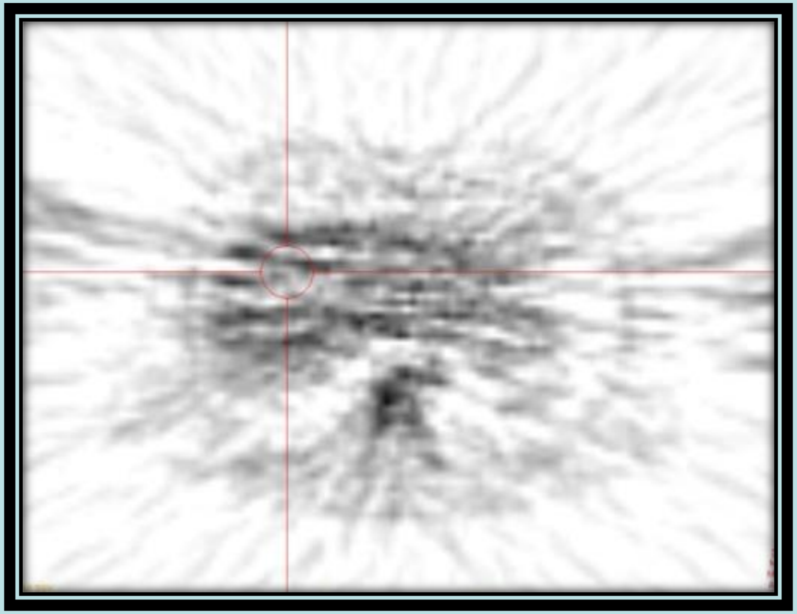


- **Filtered backprojection (FBP) and iterative reconstructions**
- **FBP is an analytic approach; does not allow modeling the noise (sensitive to noise, may contain severe streak artefacts).**

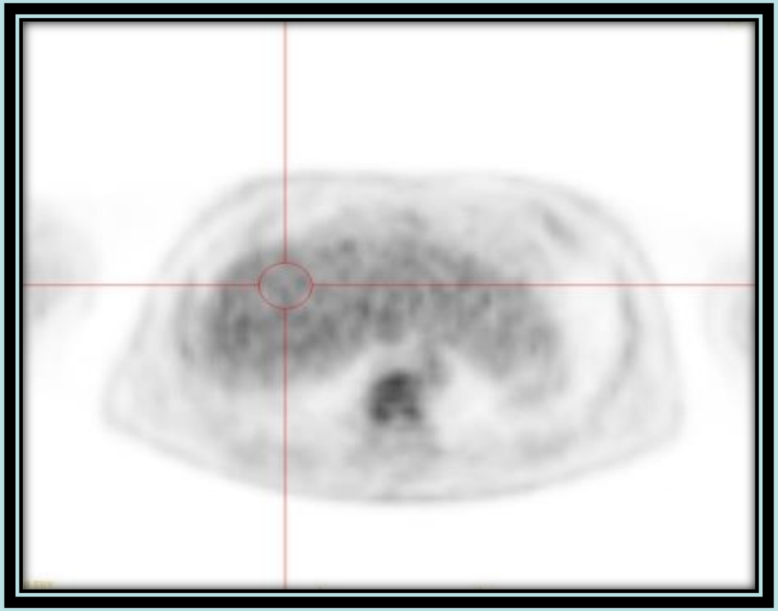
- **Iterative reconstructions outperform FBP in handling noise such that regions of low-activity concentrations can be reconstructed with better noise properties**

Comparison between FBP, OSEM

- **Reconstruction clearly provides images with better (visual) image quality.**



FBP



OSEM

Effect of Iterations and Subsets

The drawback of these methods is that both quantitative accuracy and SNR depend on the number of iterations.

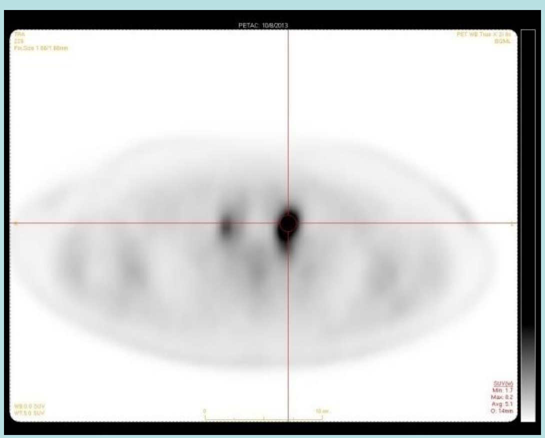
More iterations/subsets increases resolution

More iterations/subsets increases noise (decreases uniformity).

More iterations/subsets increases reconstruction time.

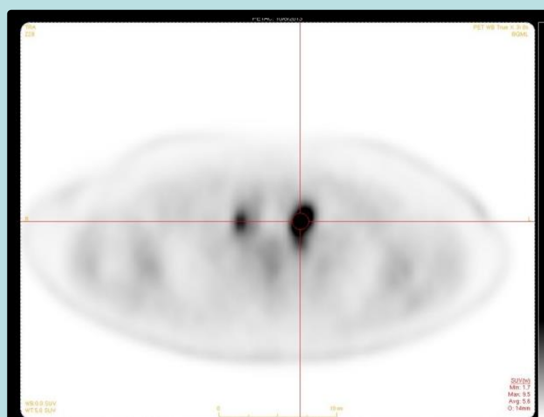
Important value is the number of updates = iterations × subsets

2i x 8s



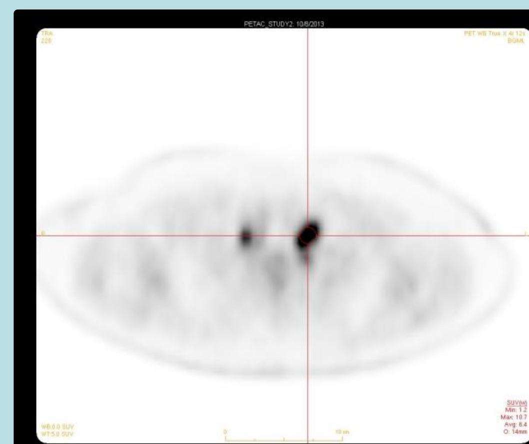
updates = 16

3i x 8s



updates = 24

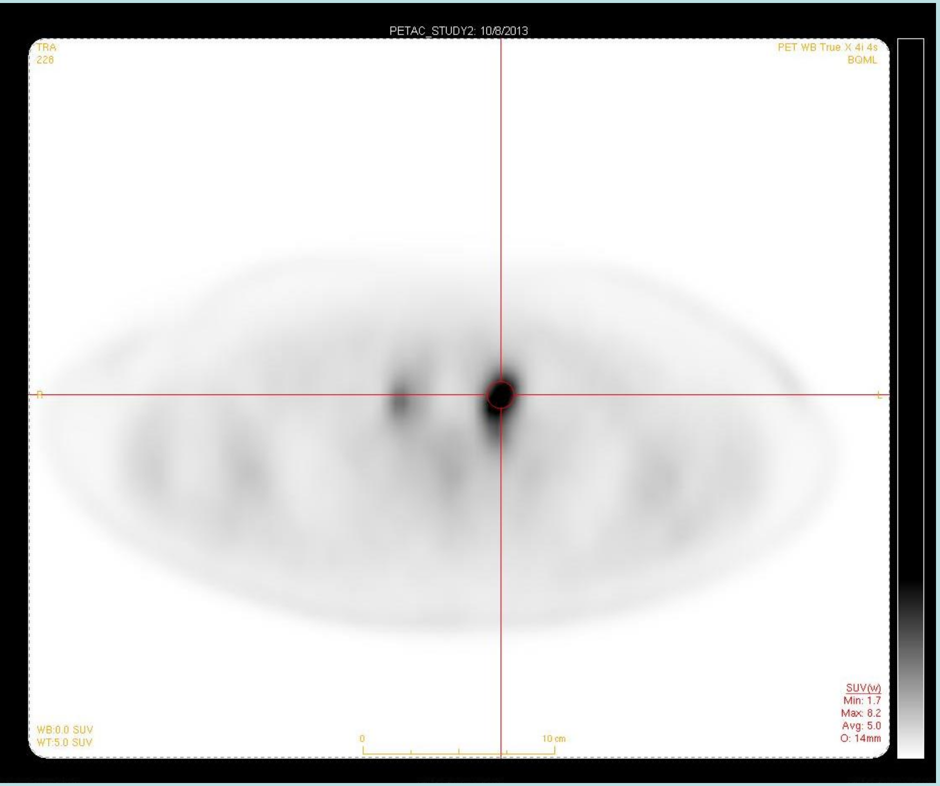
4i x 12s



updates = 48

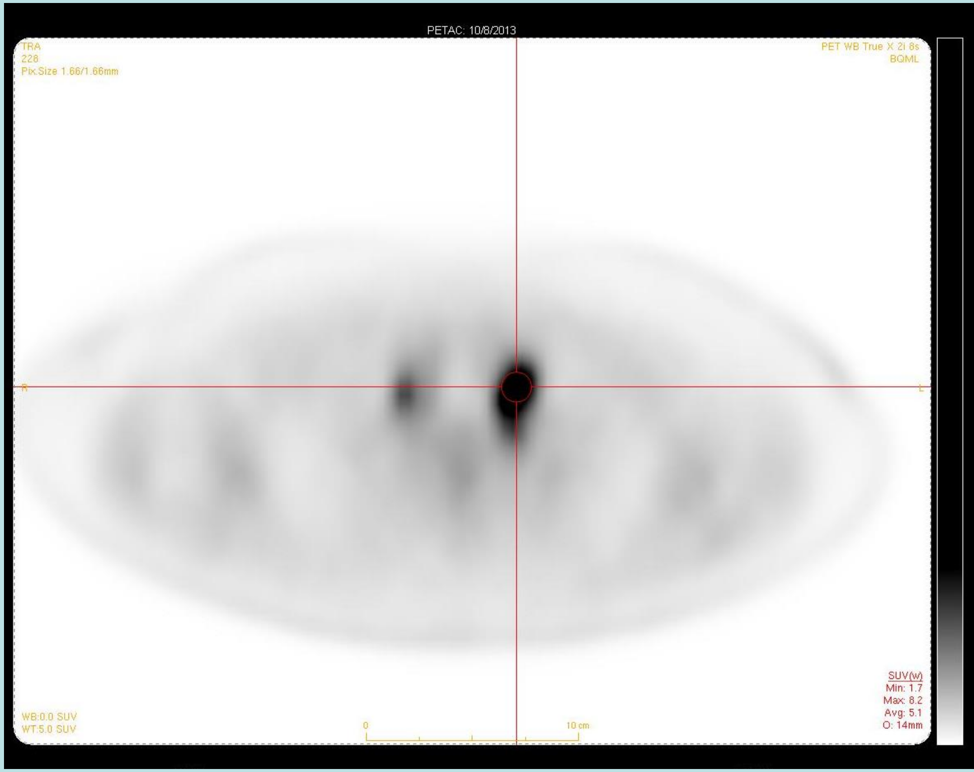
Effect of Iterations and Subsets

4i x 4s



SUVmax: 8,2
SUVmean: 5

2i x 8s

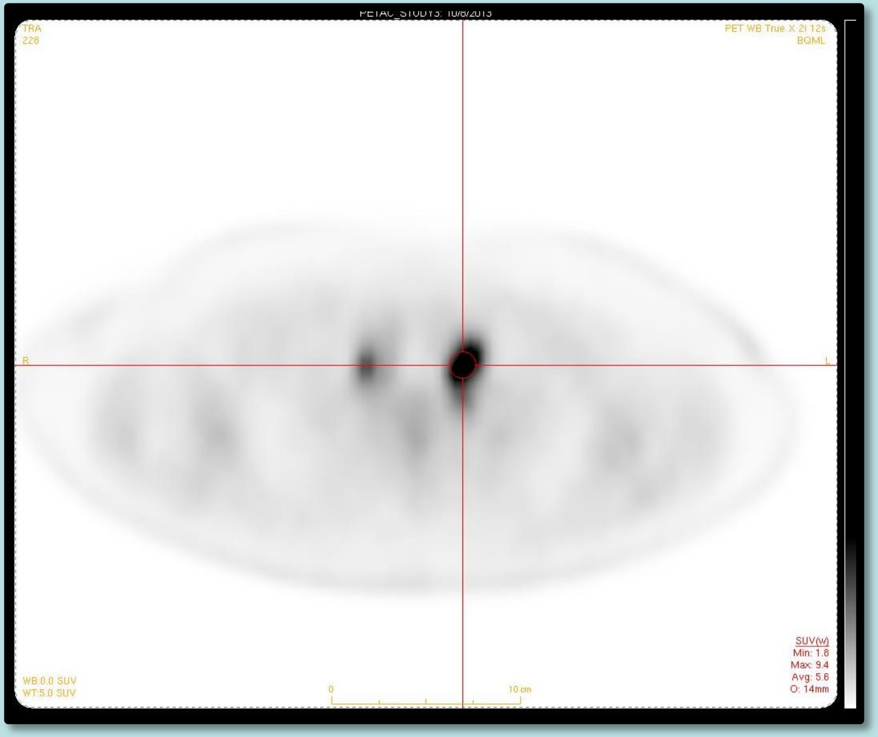


SUVmax: 8,2
SUVmean: 5,1

Updates 16

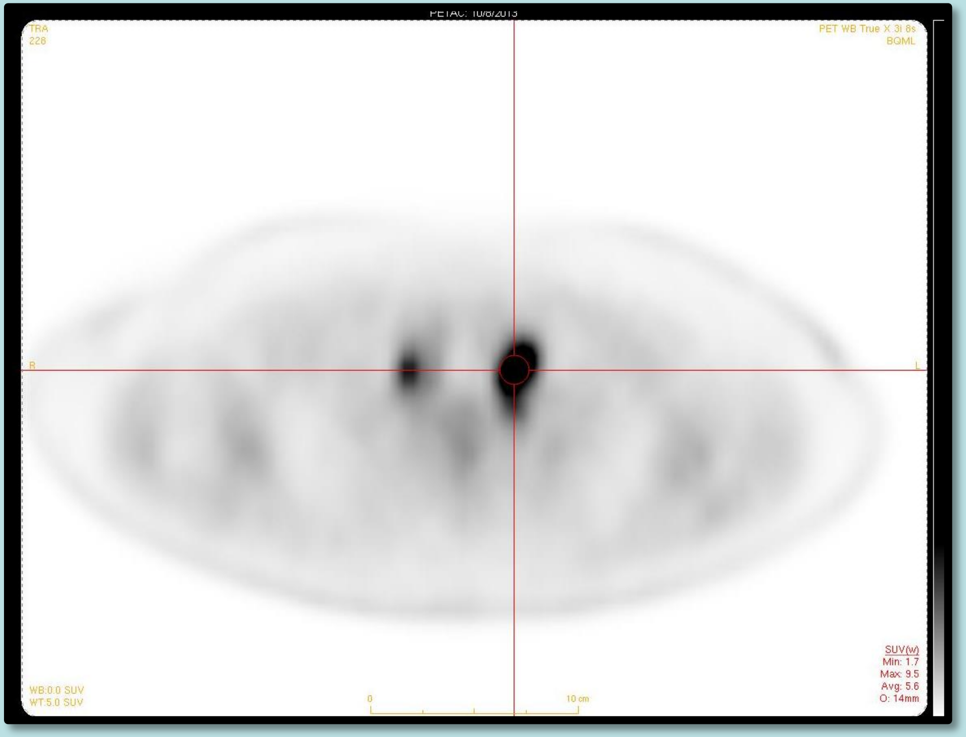
Effect of Iterations and Subsets

2i x 12s



SUVmax: 9,4
SUVmean: 5,6

3i x 8s

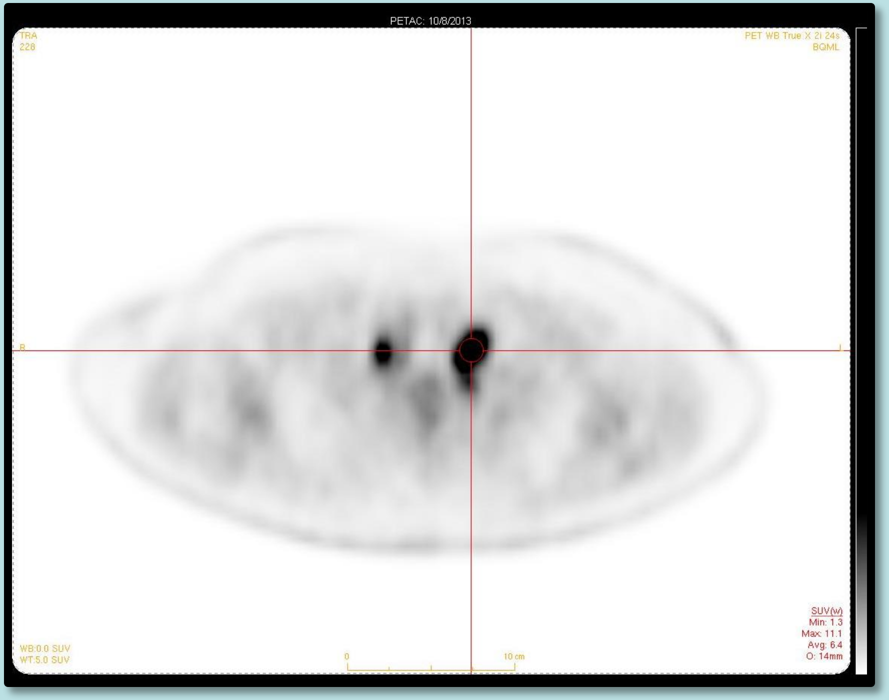


SUVmax: 9,5
SUVmean: 5,6

Updates 24

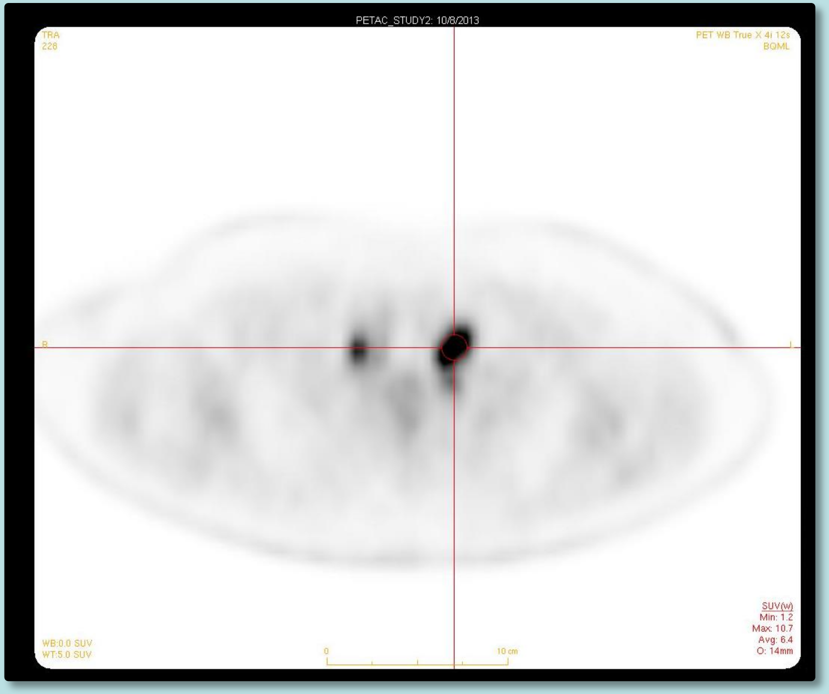
Effect of Iterations and Subsets

2i x 24s



SUVmax: 11,1
SUVmean: 6,4

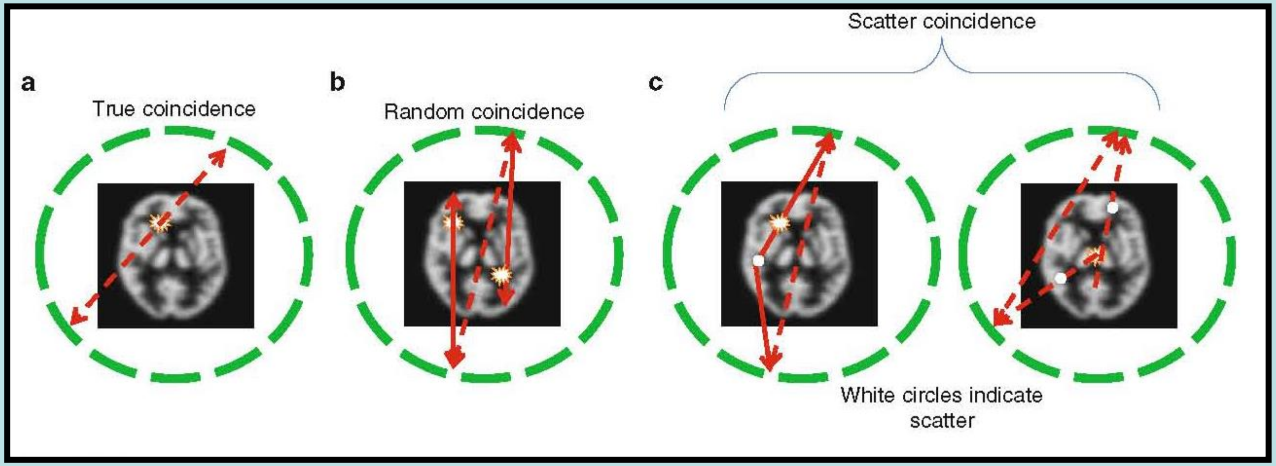
4i x 12s



SUVmax: 10,7
SUVmean: 6,4

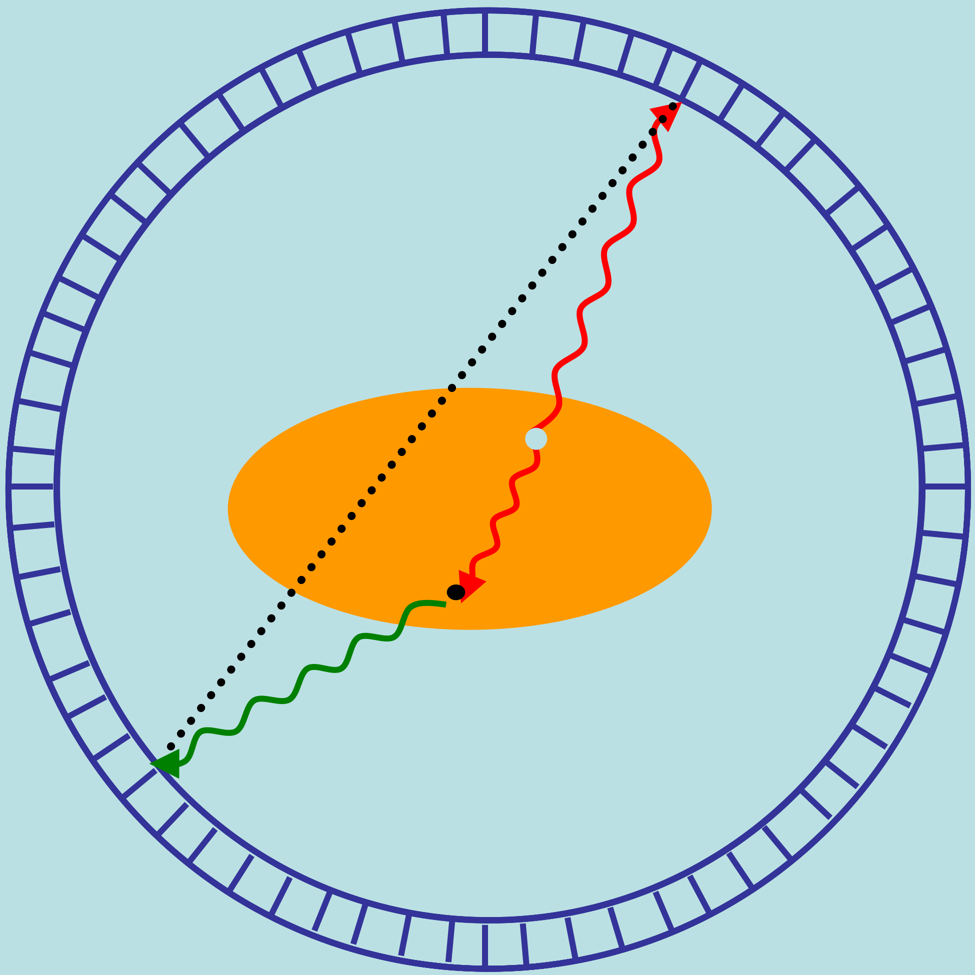
Improve Reconstruction Software

- **Reconstructions needs:**
  - **Correction for scatter.**
  - **Correction for randoms.**
  - **Correction for attenuation.**



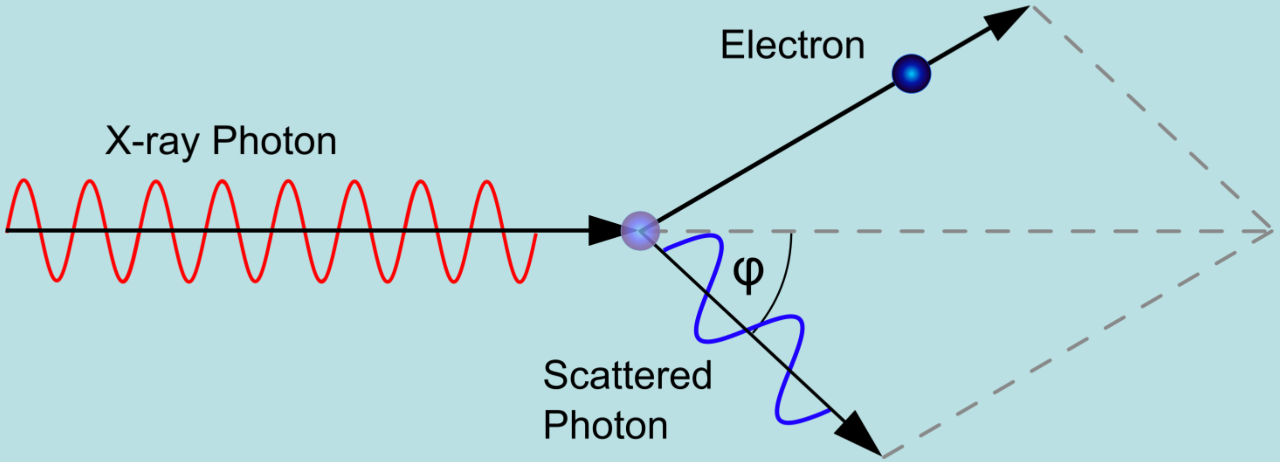
Scattered events

- Incorrect localization of the event.
- Degrades image.
- PET systems use very wide energy windows (eg 350 - 570 keV), so scatter is not efficiently rejected by energy windowing



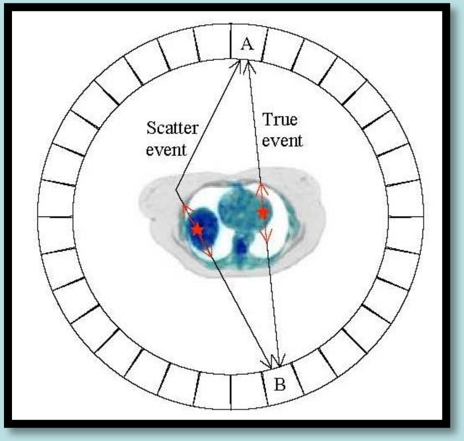
Compton scattering

- Photon interacts with electron.
- Photon has a lower energy and it abteins a diferent direction.

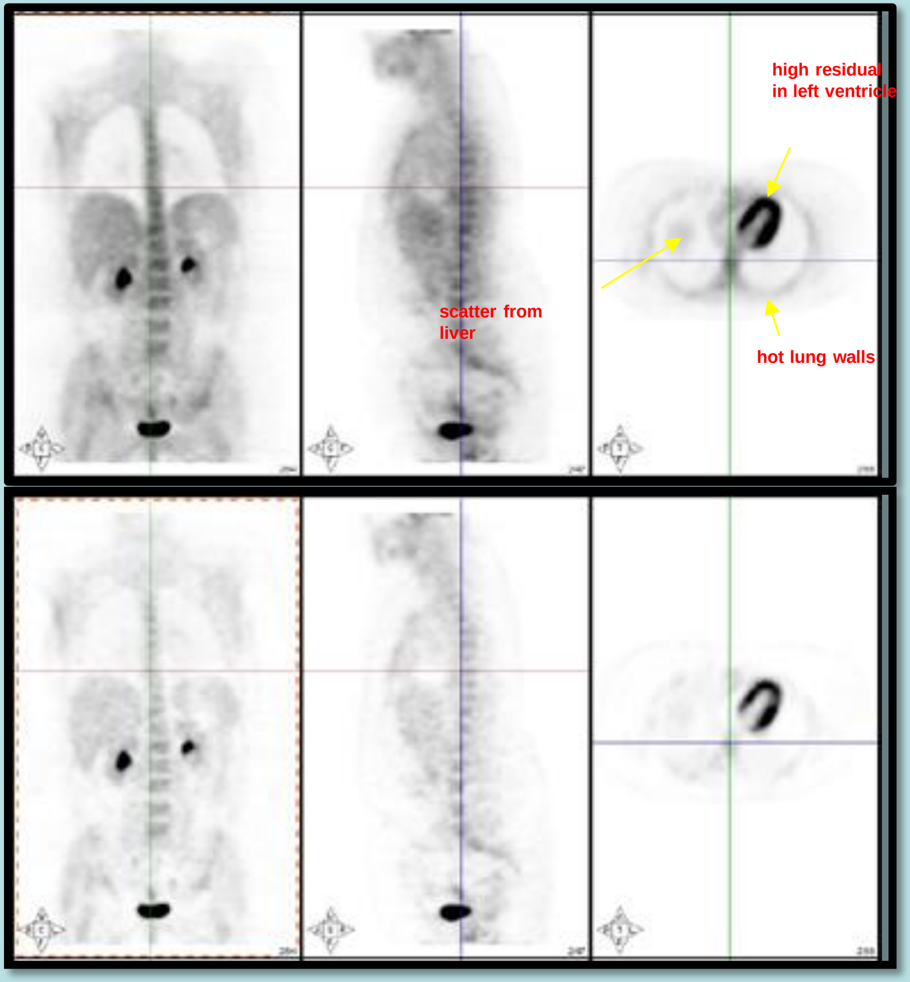


Correct for scatter

Uncorrected



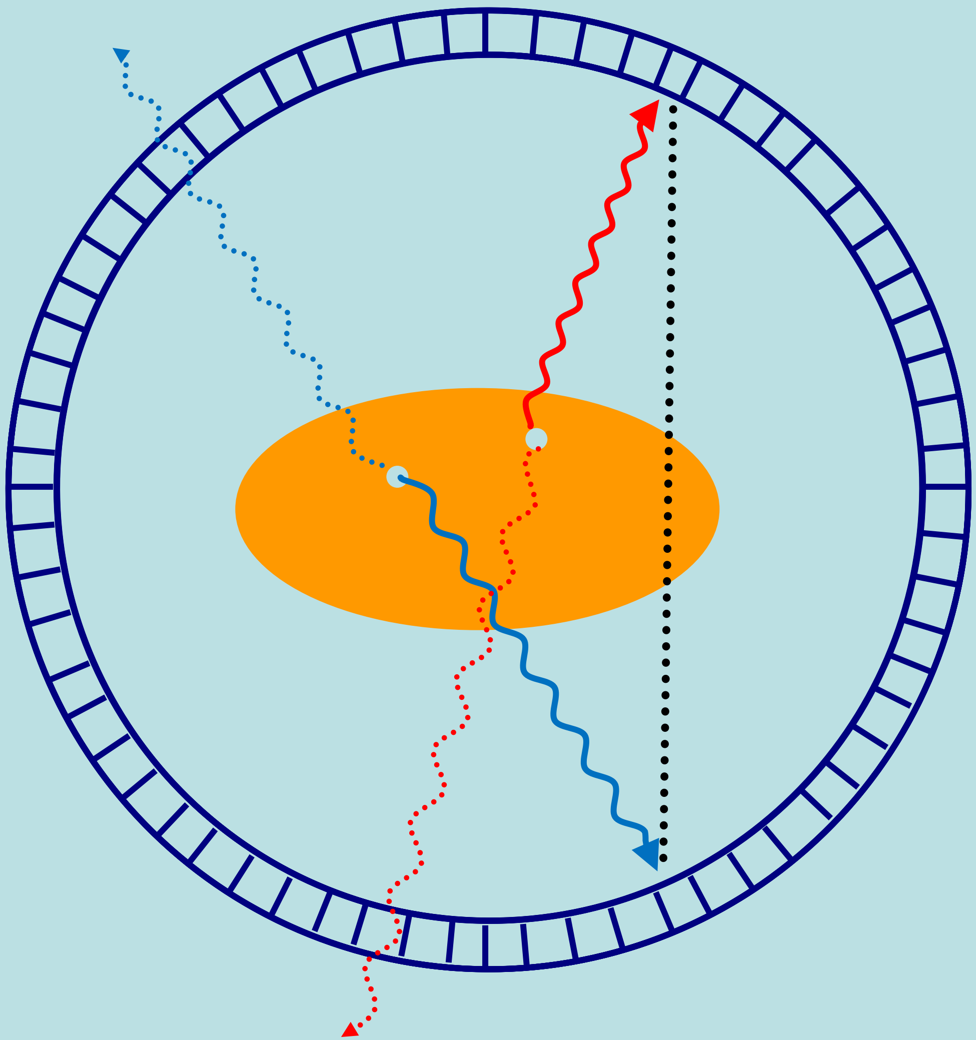
Scatter corrected



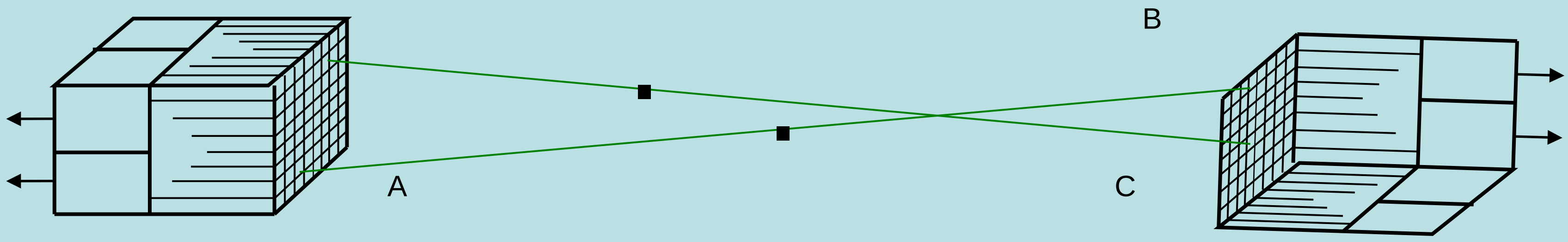
Highly efficient, model-based Compton scatter correction system using Monte Carlo-based computational techniques.

Random Events

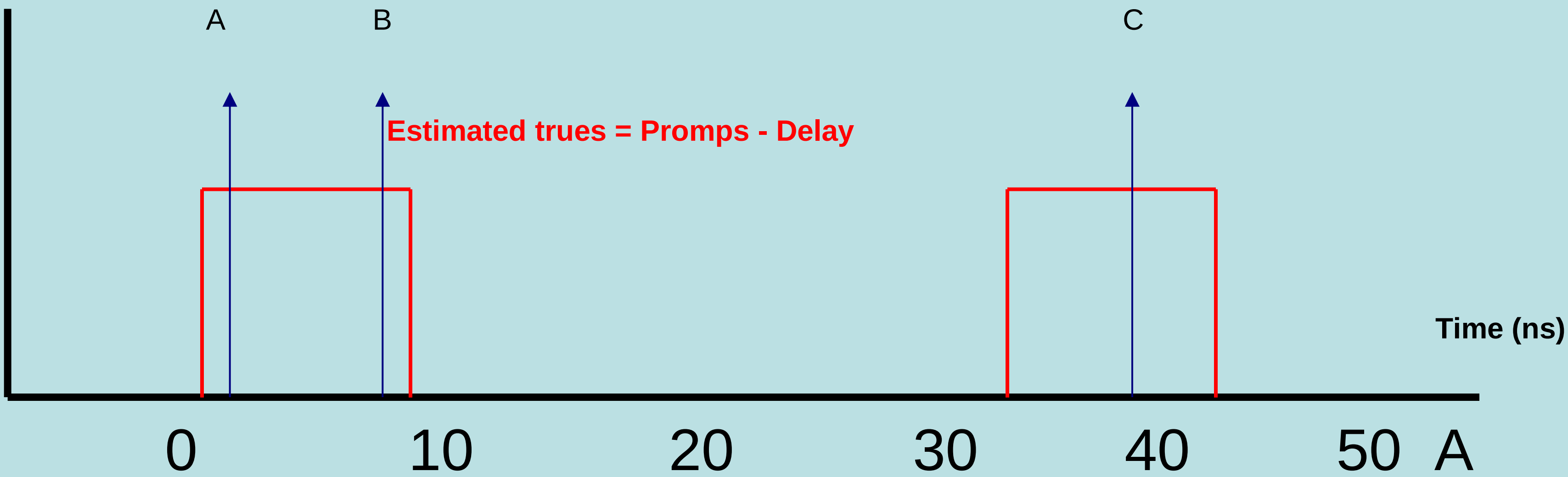
- **2 <u>separate</u> annihilations are detected within the timing window.**
- **The event will be localized along a path that does not correspond to the origin of the photons.**
- **The random fraction of events <u>increases with the dose</u> of administered activity**



Delay window method; Random estimation



Promps= Trues + Randoms **Delay = Randoms only**



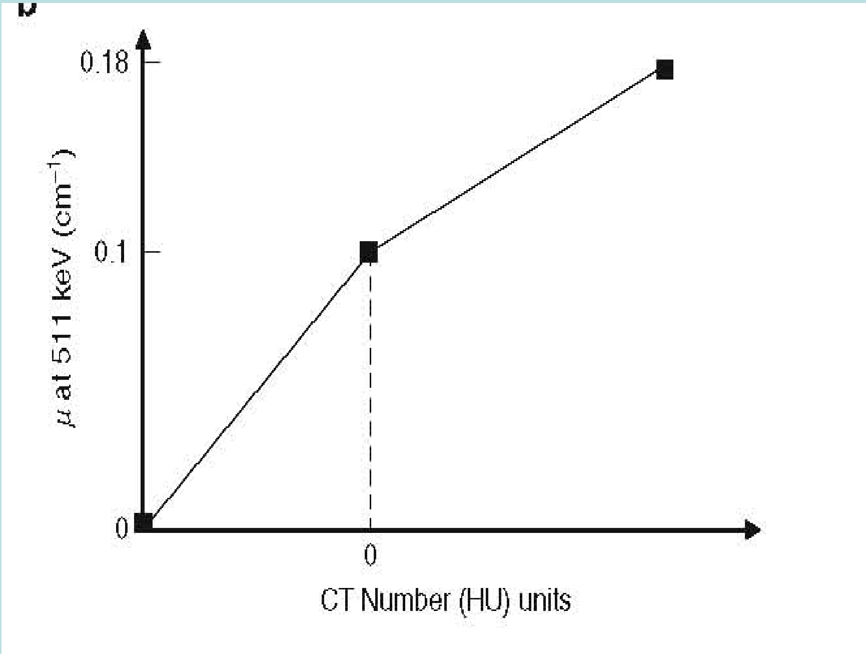
A randoms-corrected sinogram can then be obtained by subtracting this randoms sinogram from the measured total coincidence sonogram, resulting in a ‘trues’ sinogram.

Attenuation Correction

- **Essential as > 60 % of emitted photons interact with tissue**
- **Requires a map of linear attenuation coefficients from transmission scan using:**
  - **Germanium-68 rod sources**
  - **Caesium-137**
  - **X-ray CT**

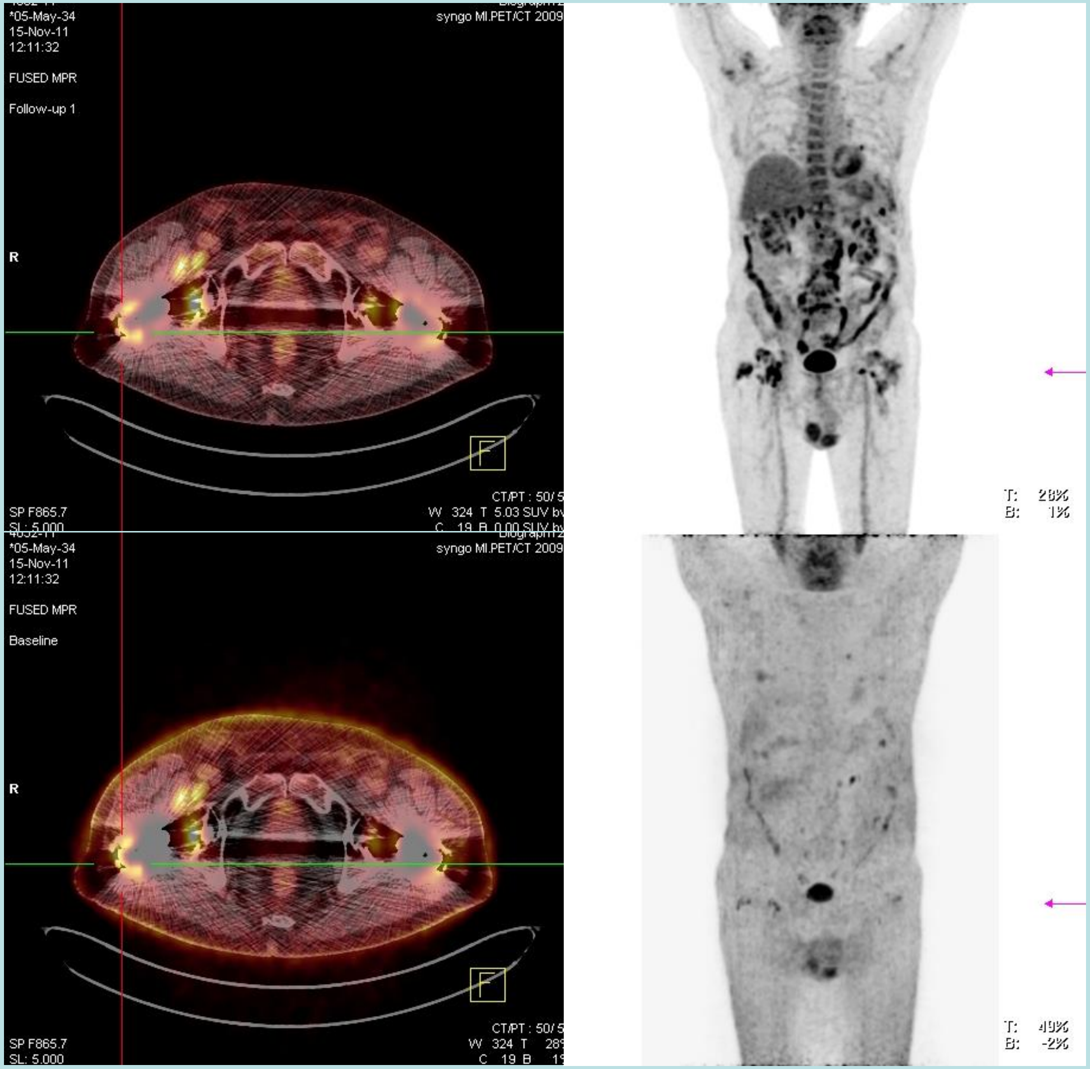
Hounsfield unit (HU)

Bone	+400	+1000
Soft tissue	+40	+80
Water	0	
Fat tissue	-60	-100
Lung	-400	-600
Air		-1000



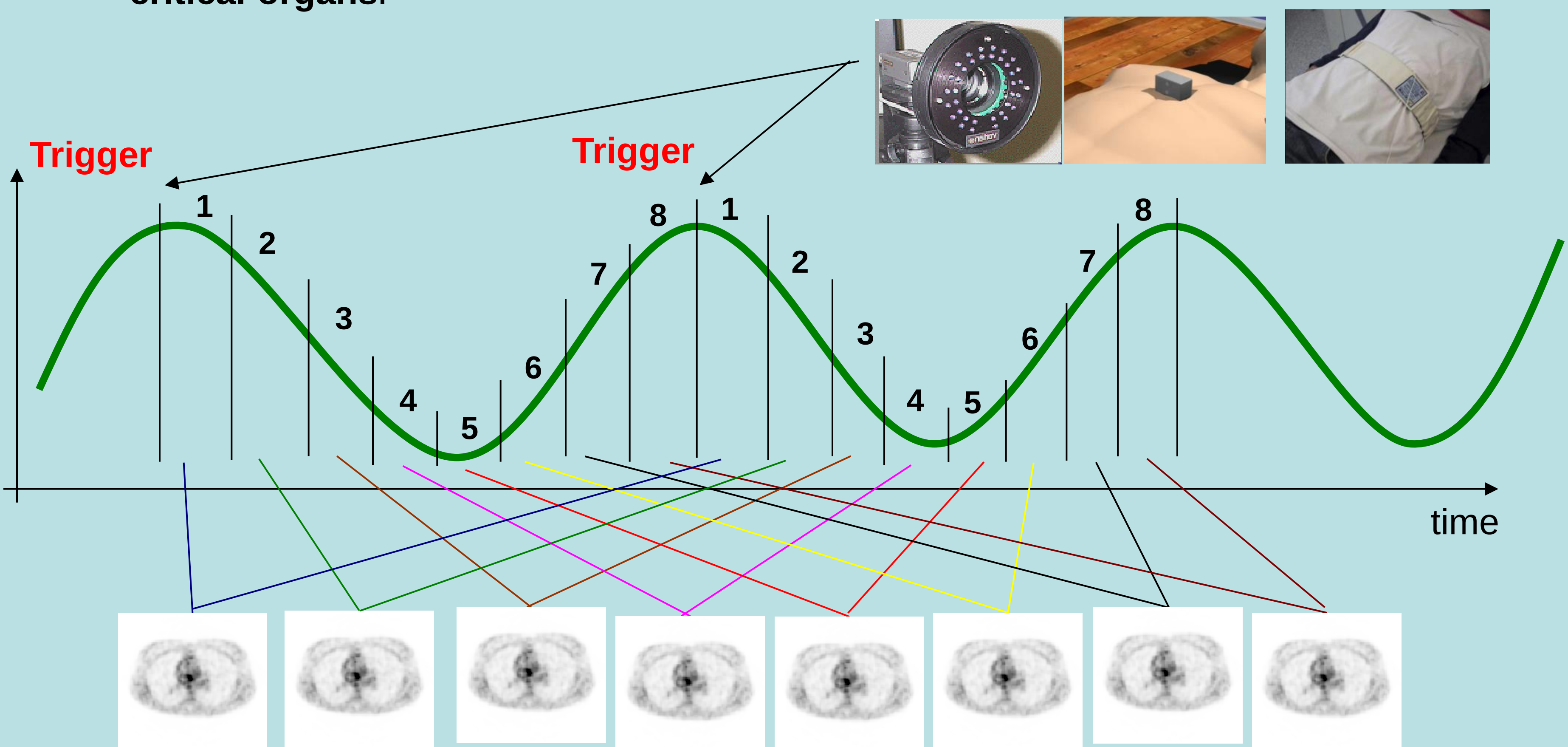
Bilinear transformation curve uset in CT based attenuation corection in PET

Metal artefact



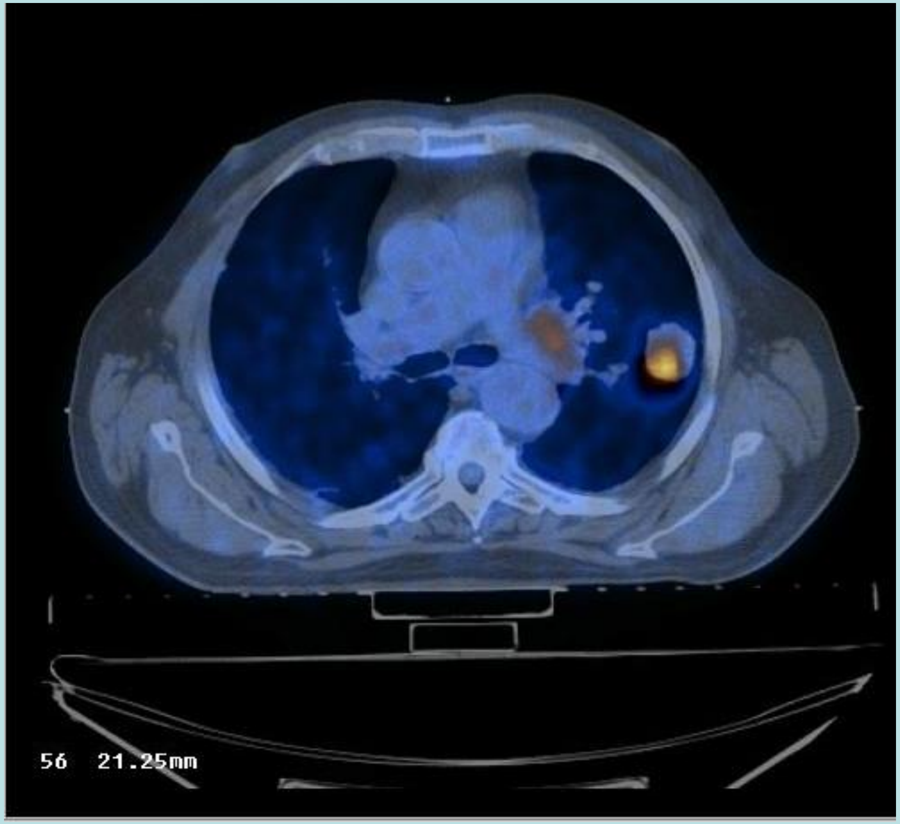
System Developments
Motion gated imaging 4D PET-CT

- **Respiratory tracking with Varian RPM optical monitor**
- **CT images acquired over complete respiratory cycle**
- **Captures the internal movement of organs and the tumor over time.**
- **Creates the most complete and accurate imaging information of tumor and critical organs.**



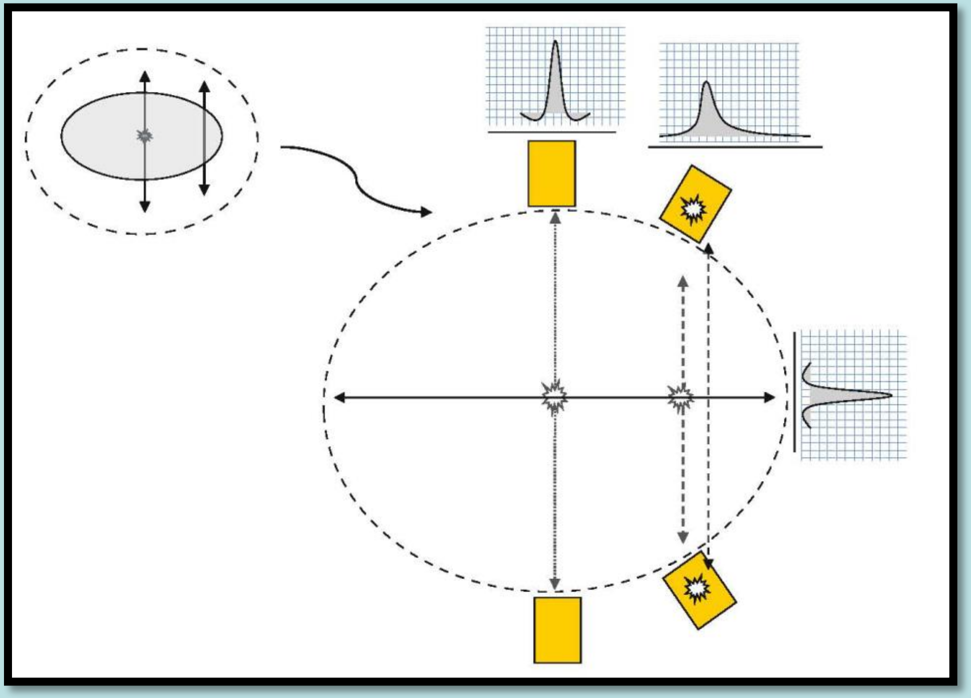
Bin 1 **Bin 8**

Motion artefact



Advances in PET image reconstruction algorithms

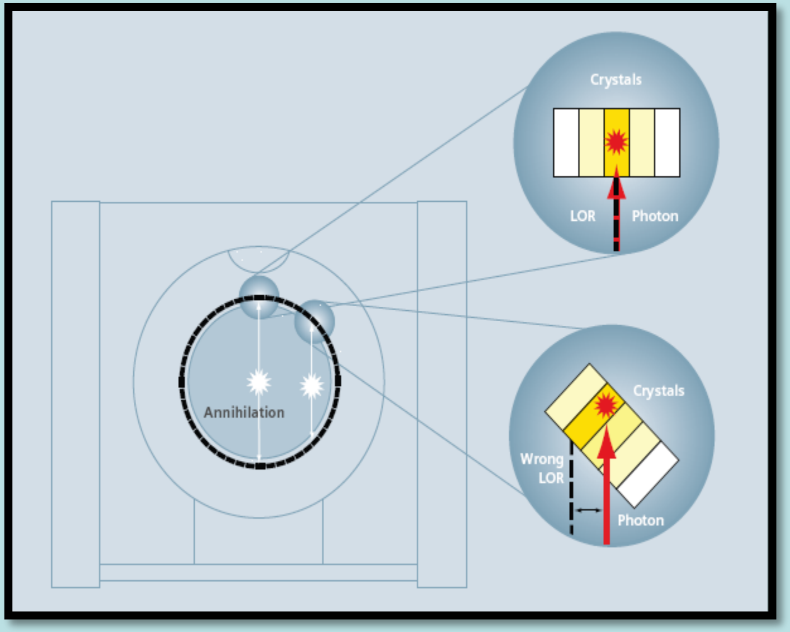
- The iterative OSEM algorithm was used initially and has been improved. (True X reconstruction)
- Recent technologies: resolution recovery (PSF), TOF.

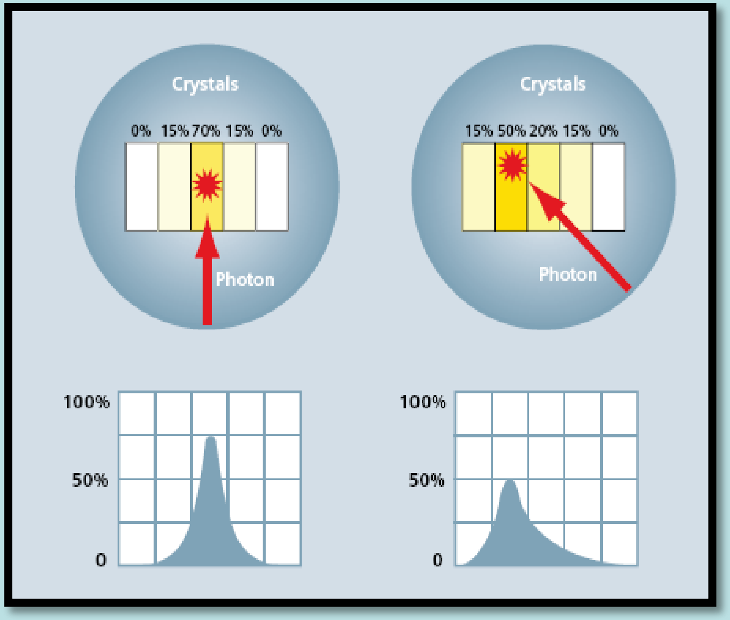


1. Liu X, Comtat C, Michel C, et al: Comparison of 3-D reconstruction with 3D-OSEM and with FORE+OSEM for PET. IEEE Trans Med Imaging 20:804-24, 2001

2. Panin VY, Kehren F, Michel C, et al: Fully 3-D PET reconstruction with system matrix derived from point source measurements. IEEE Trans Med Imaging 25:907-21, 2006

Detector/PSF Modelling

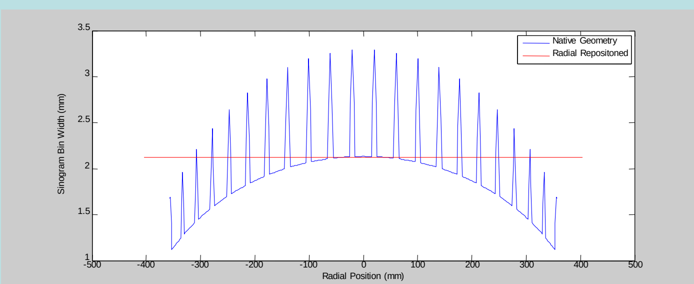


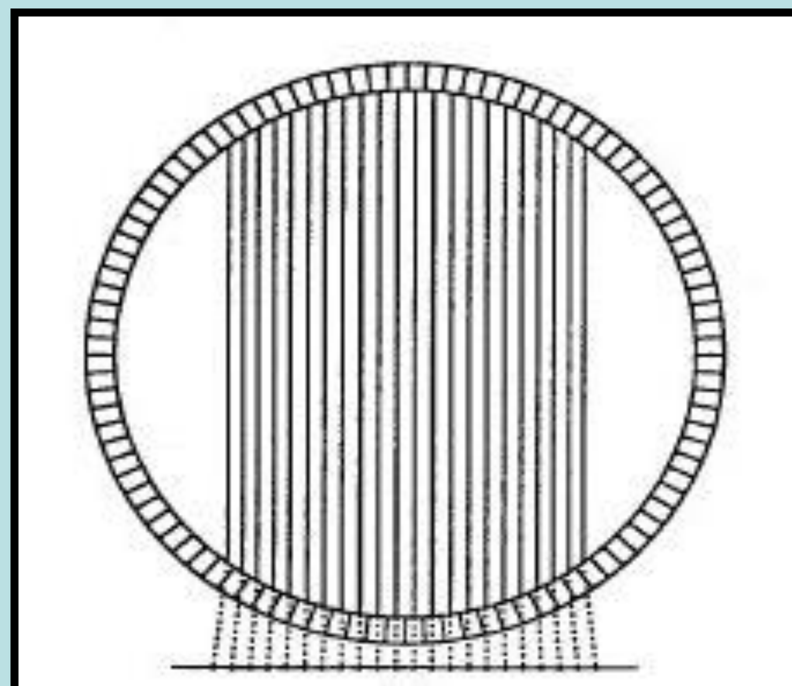


- When a photon strikes a crystal, it travels a certain distance before its energy is converted into light.
- If the photon comes from the center of the field of view (FOV), the line of response (LOR) is likely to be correctly localized in the crystal in which the photon entered.
- The further away from the center of the FOV, the less likely the LOR will be calculated correctly because the photon will hit the crystal at an angle and continue traveling to another crystal before it lights up.

Point Spread Function (PSF)

Describes the response of an imaging system to a point source or point object.
A system that knows the response of a point source from everywhere in its FOV can use this information to recover the original shape and form of imaged objects.

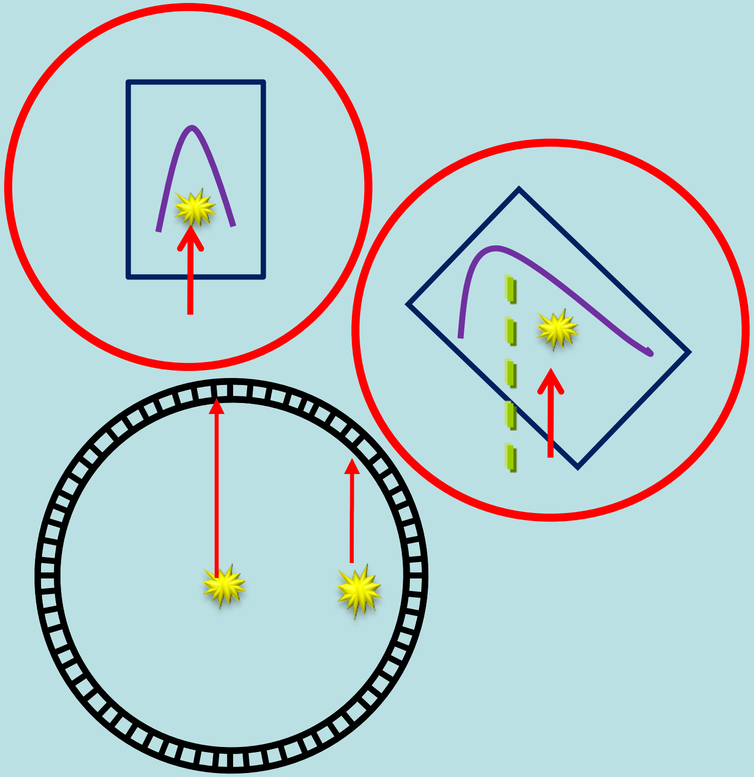




Conventional PET

- **Same reconstruction principles across the entire FOV and does not take into account the detector geometry and mispositioning of the LORs.**

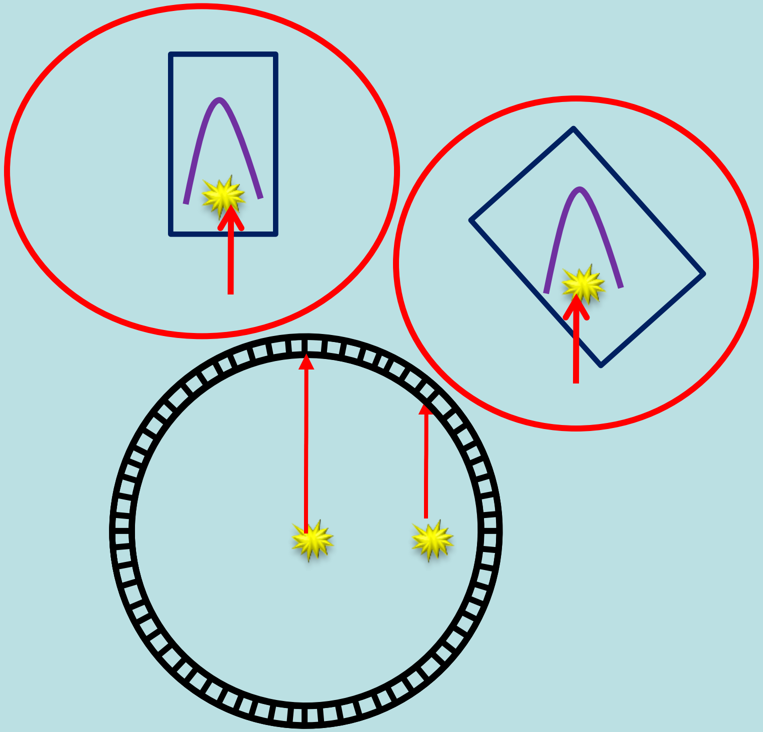
- **This results in fuzzy edges and increased distortion further from the center of the FOV**



HD•PET

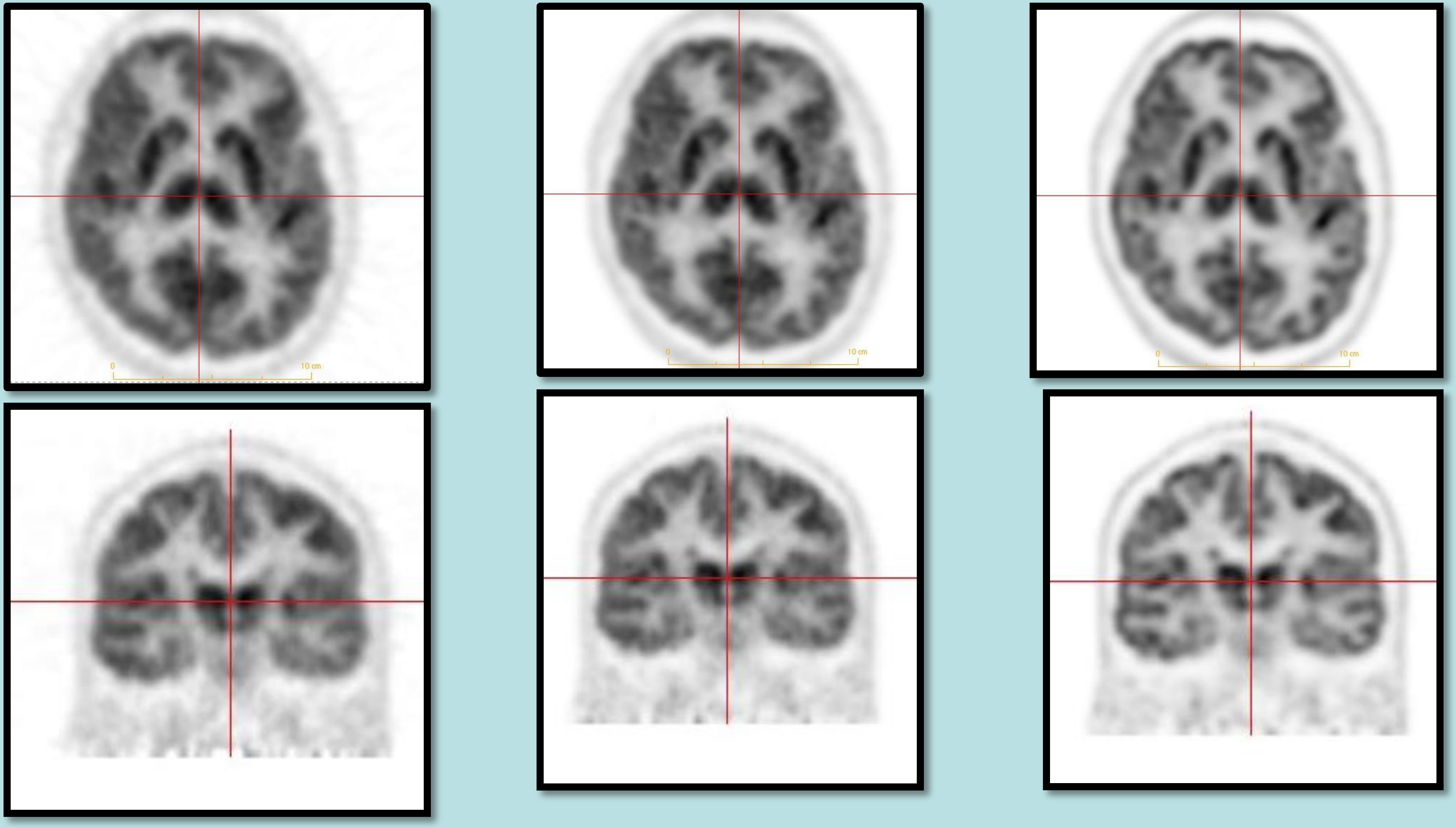
- **Incorporates millions of accurately measured point spread functions in the reconstruction algorithms.**

- **Using measured PSFs, HD•PET effectively positions the LORs in their actual geometric location, which dramatically reduces blurring and distortion in the final image.**



HD PET; modeling de sistem PSF

FBP **iterative** **True X**

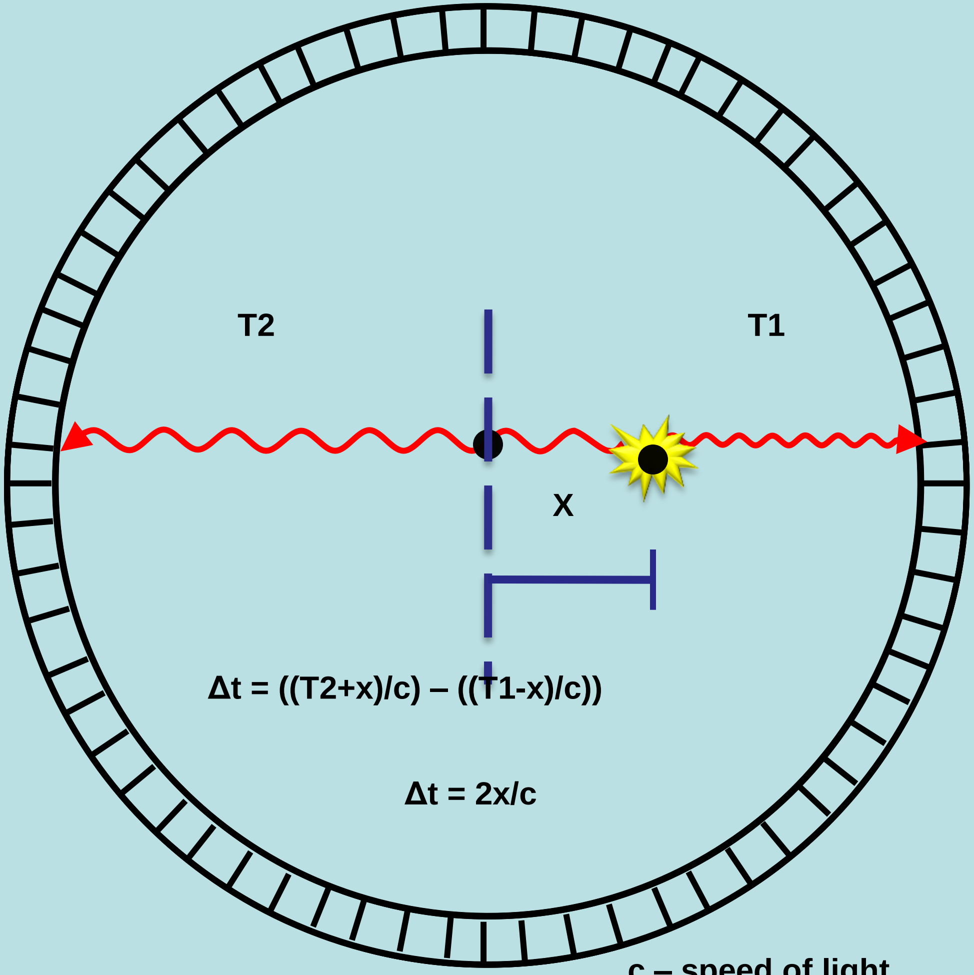


Time of flight

- The principle of TOF is based on the measurement of the time difference in the arrival of the two annihilation photons at the respective detectors.

- TOF PET results in a further improvement in SNR.

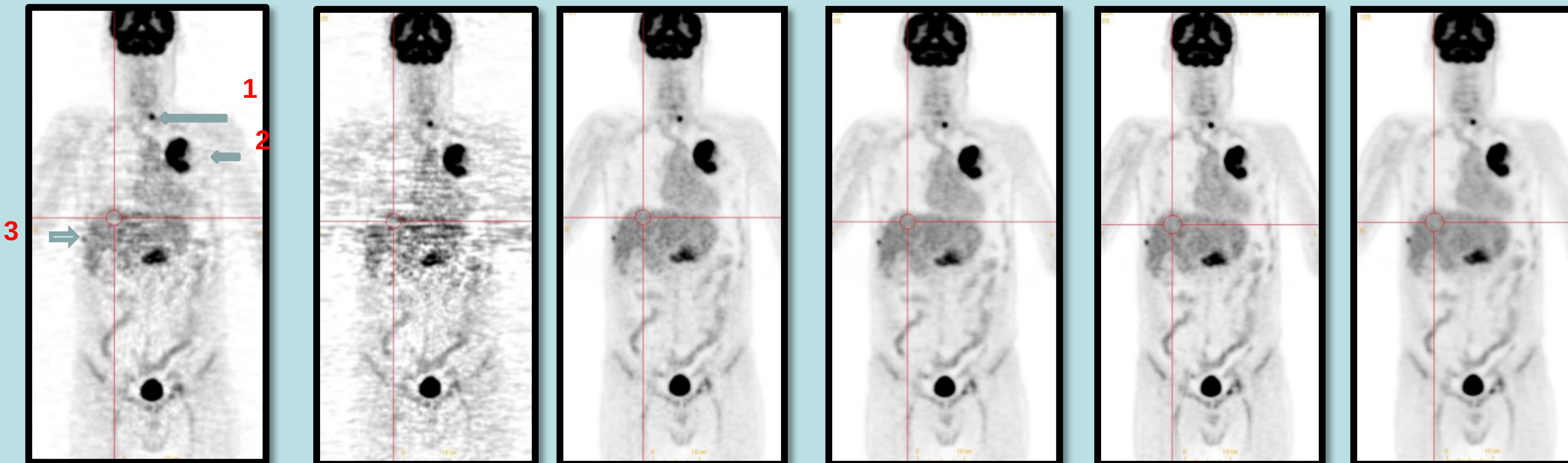
- Δt = 300psec; x~4.5cm
- Δt = 600psec; x~9.0cm
- Δt = 30psec; x~4.5mm



c – speed of light

Joel S. Karp Benefit of Time-of-Flight in PET: Experimental and Clinical Results JNM Vol. 49 • No. 3 • March 2008

Reconstruction algorithms and quantification



SUVmax / SUVmean

	FBP+TOF	FBP	iterative	True x 2i 24s	True x TOF 2i 21s	True x TOF 1i 21s
1	5.2 / 3	5.7 / 3.1	6.1 / 3	6.8 / 3.2	7.2/ 3.1	5.7/ 2.9
2	12.5 / 7.2	13.4 / 7.4	13.6 / 7.2	14.5 / 7.5	14.1 / 7.3	13.3 / 7.3
3	3.5 / 2	4.3 / 2.1	3.7 / 2.4	4 / 2.4	4.4 / 2.7	3.7/ 2.5

1 FBP SUVmax

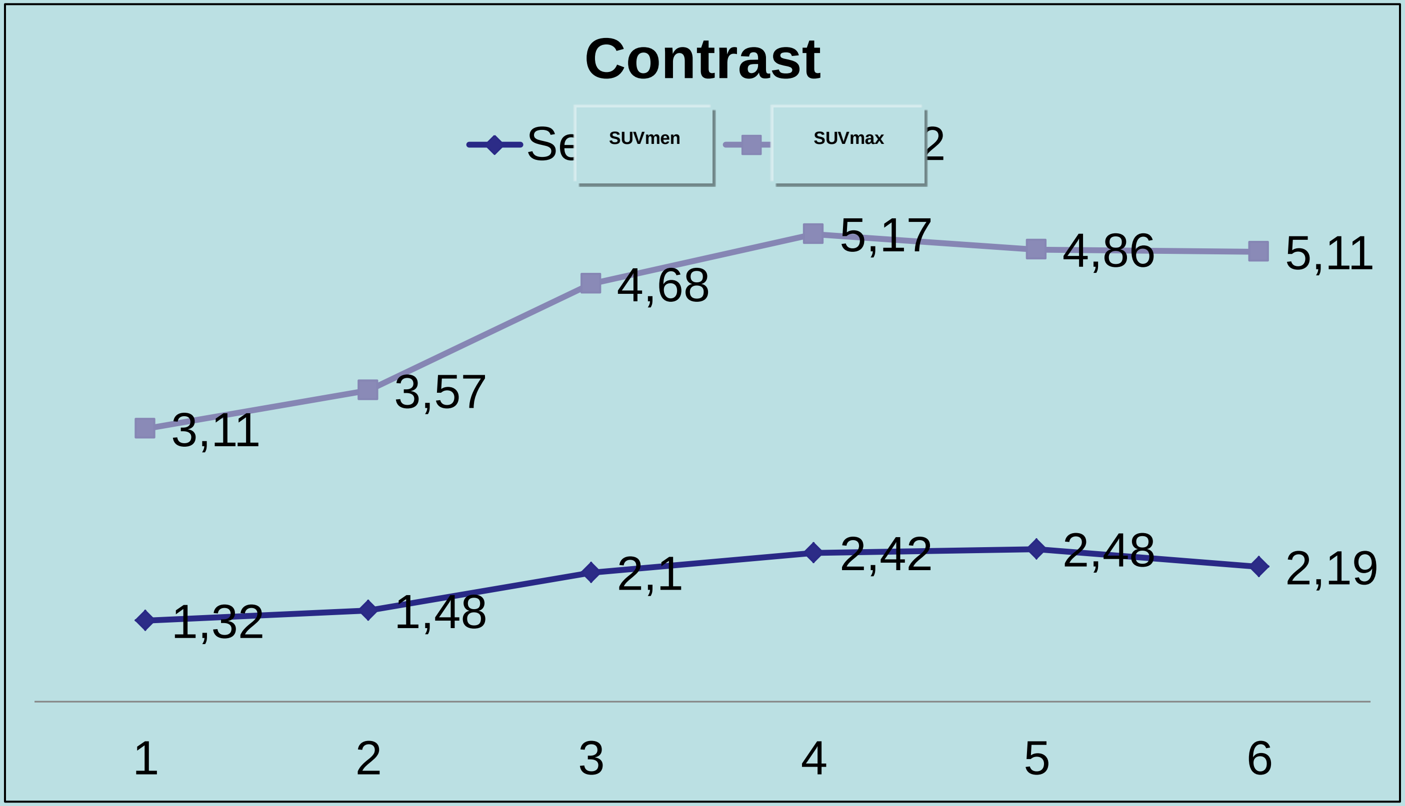
2 FBP_TOF SUVmax

3 Iterative 2i 24s

4 TrueX

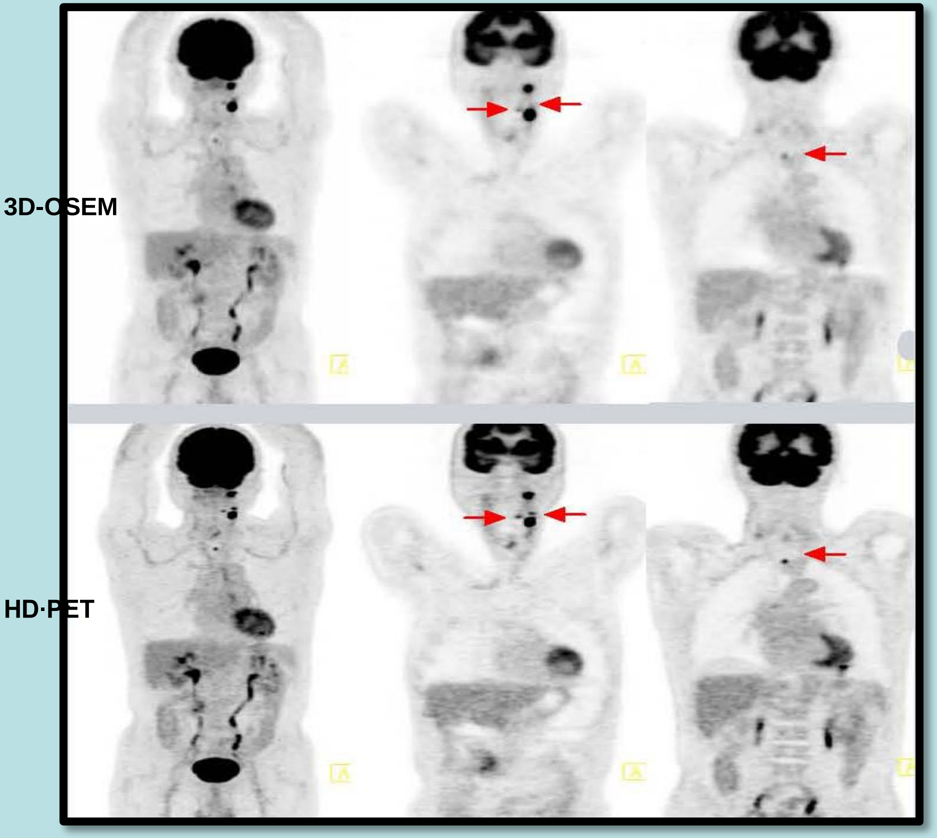
5 TrueX tof 2i 21s

6 Truex tof 1i 21s



Contrast= SUVmax hot spot / SUVmax background

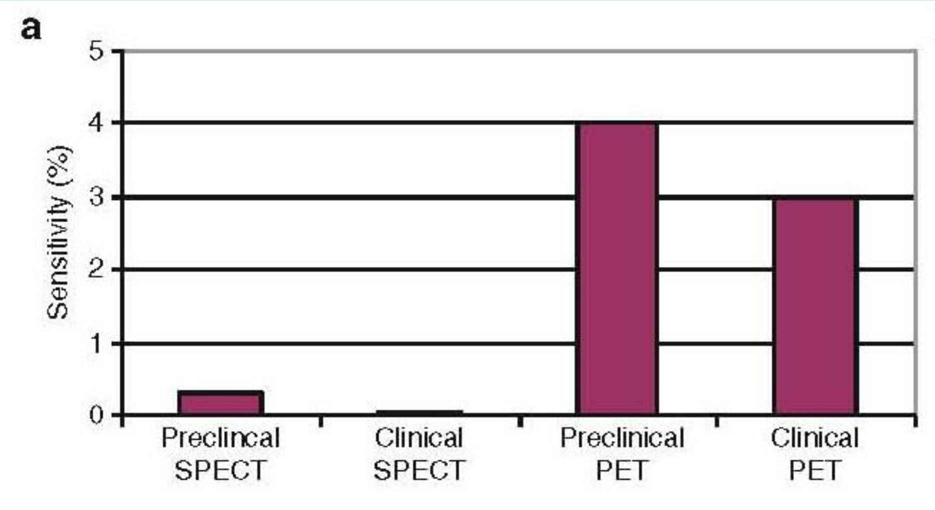
Advances in PET image reconstruction algorithms

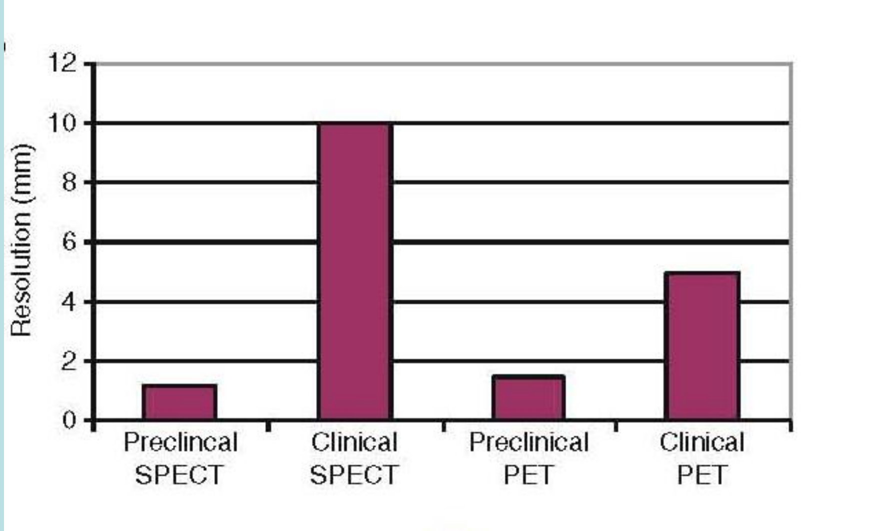


HD –PET includes:

- Fully 3D iterative reconstruction
- Improved signal-to-noise ratio
- High contrast-recovery coefficients
- Provides excellent spatial resolution
- Calculates scatter coincidence distribution
- Detecting Small Lesions in High-Activity Backgrounds

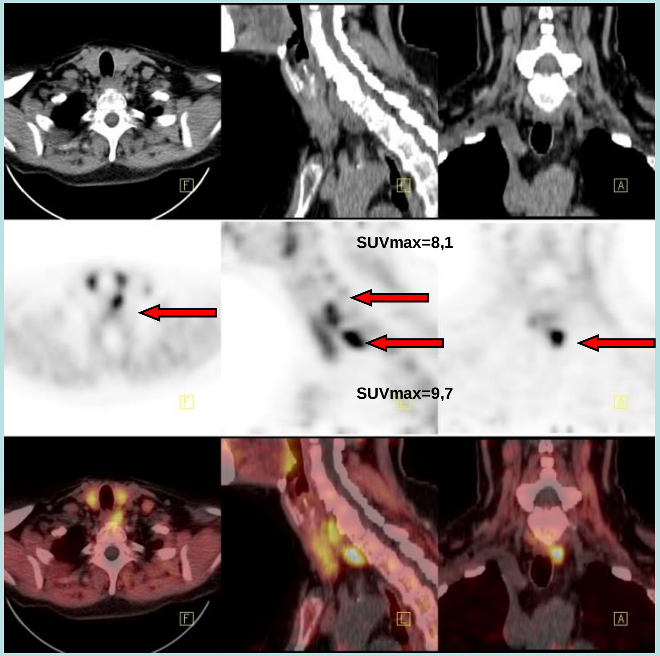
PET & SPECT- sensitivity & resolution



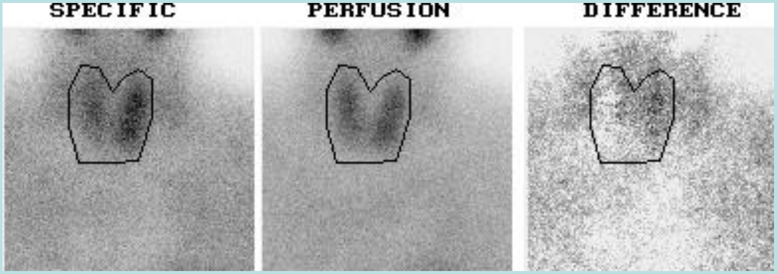


PET/CT & SPECT/CT & SUBTRACTION SCINTI

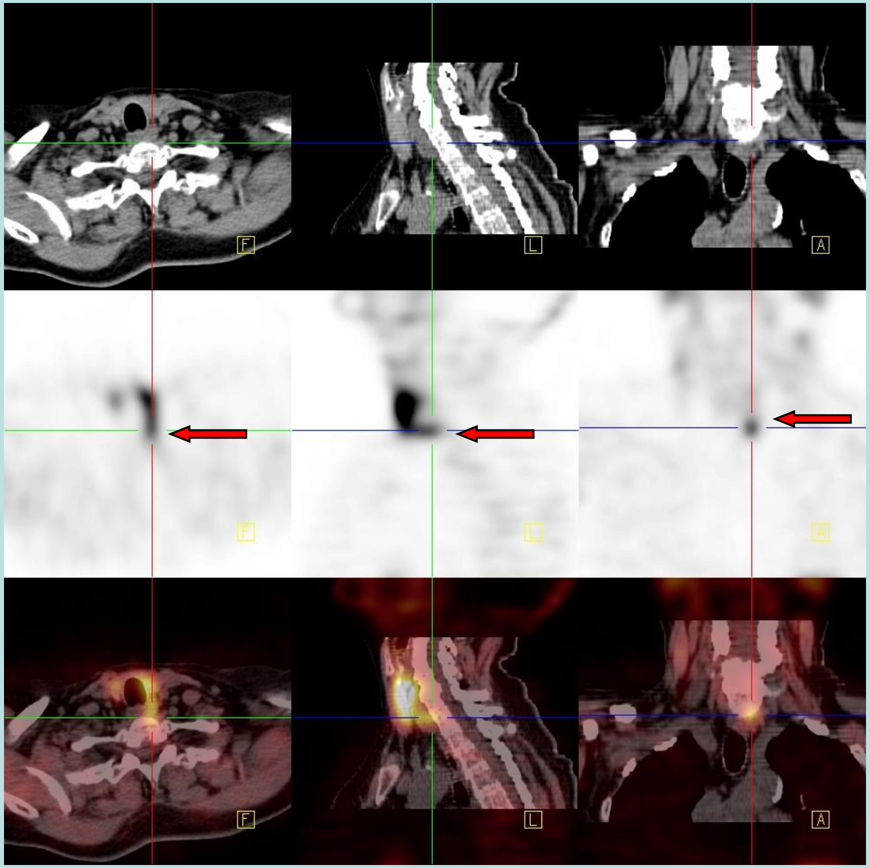
PET/CT



SUBTRACTION SCINTI



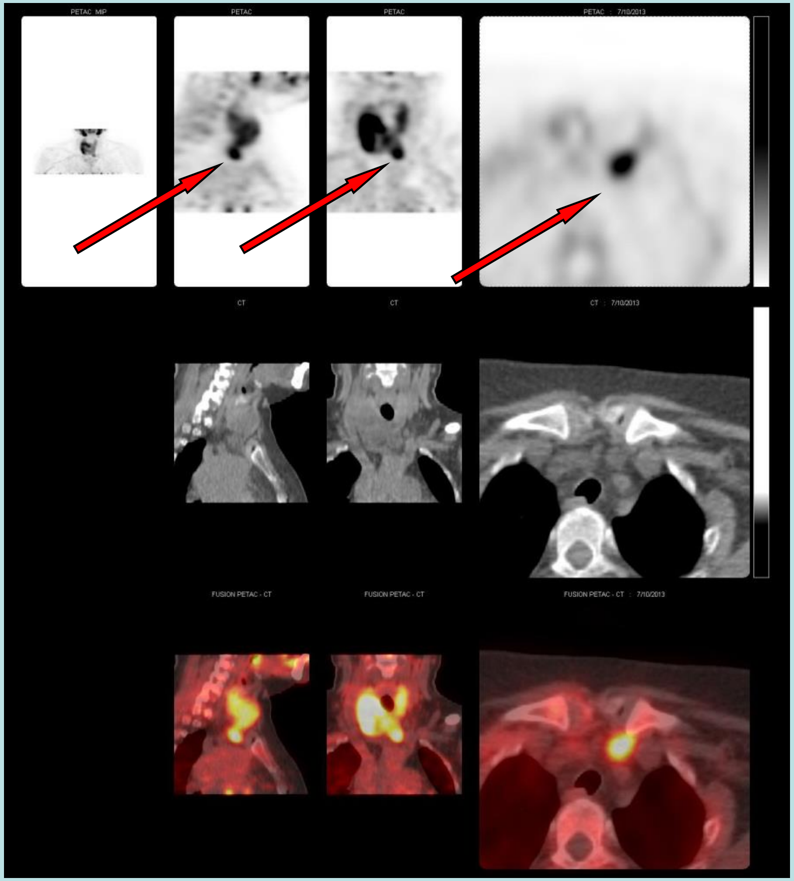
SPECT/CT



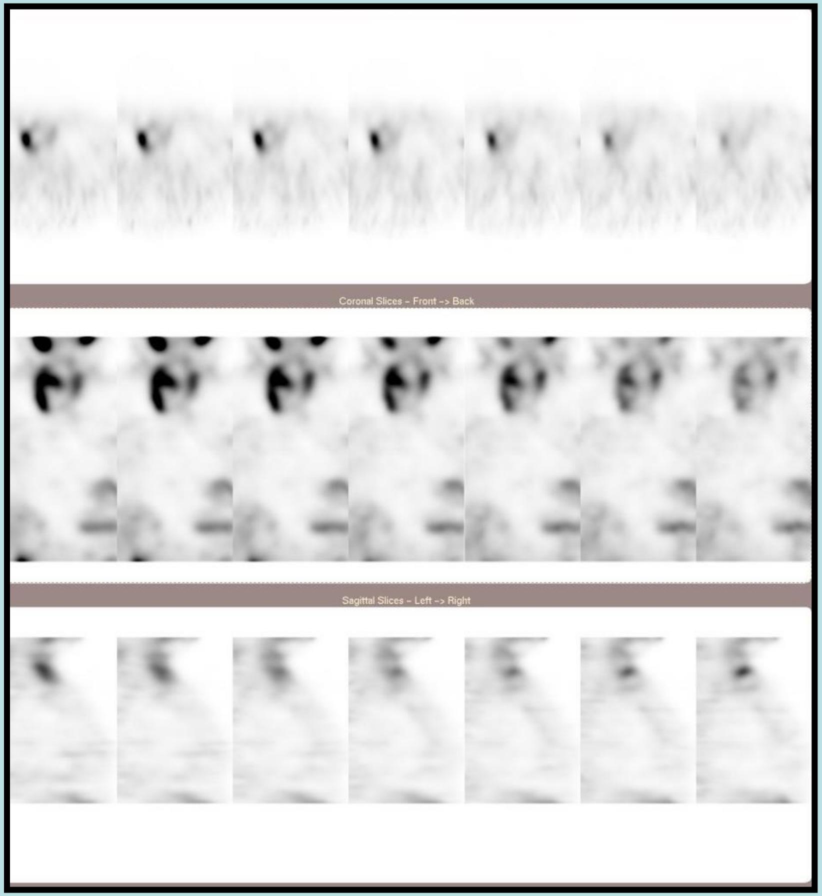
Left lower- SUVmax=9,7; Left apper- SUVmax=8,1
Ca 2,82mmol/l ; iPTH 357ng/l after Ca 2,39 iPTH 50,3

PET & SPECT

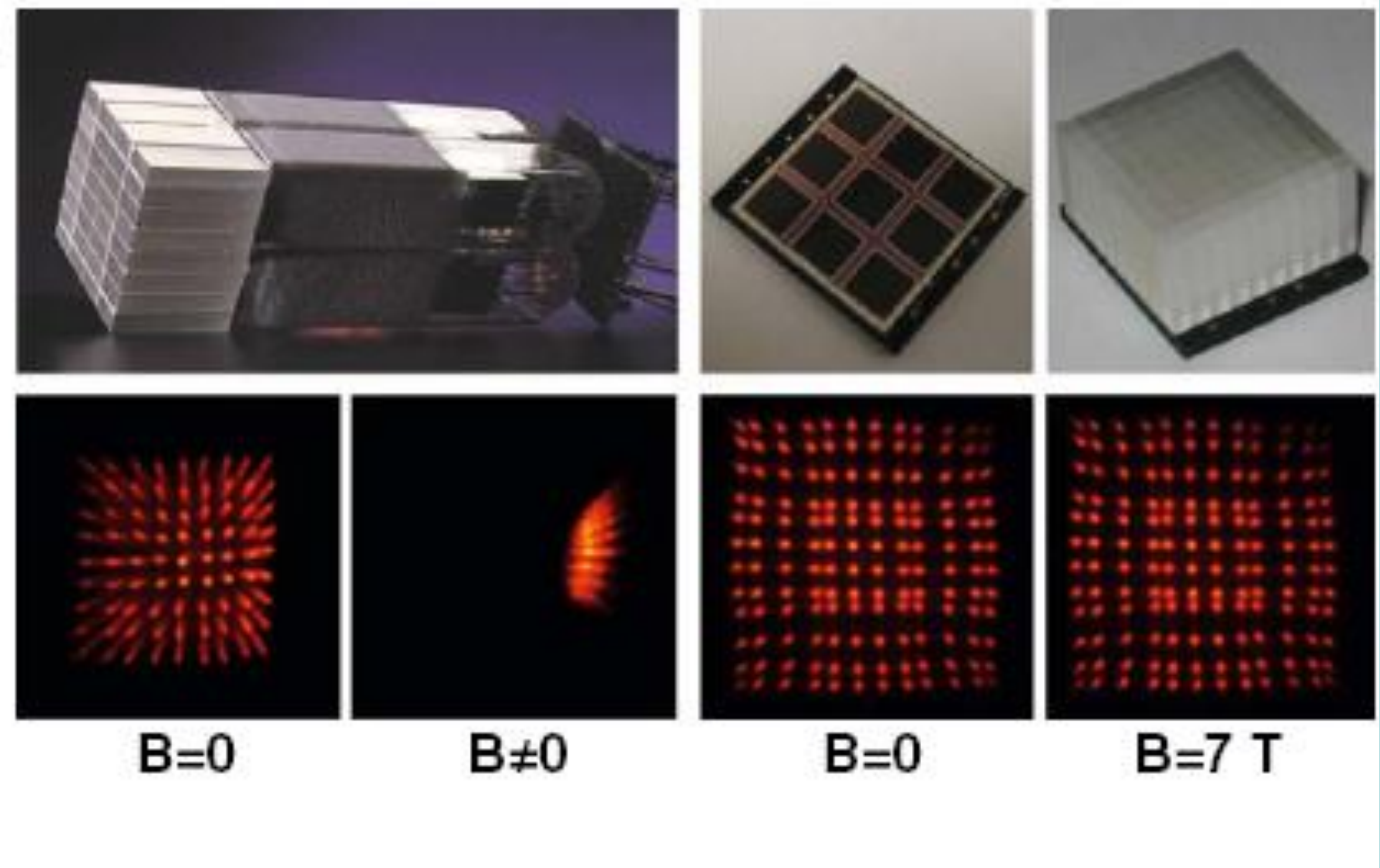
PET



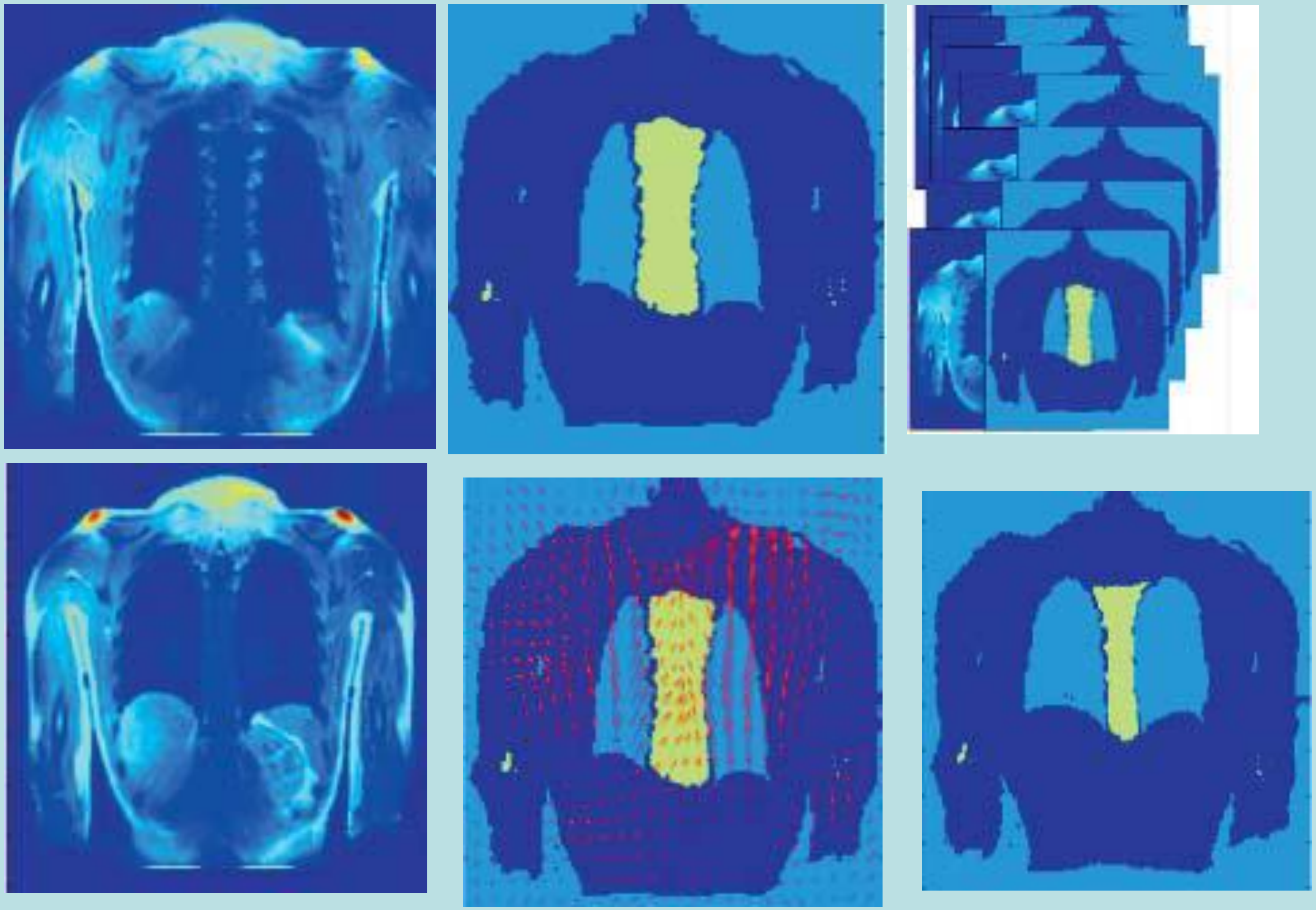
SPECT



PET/MR



MR-CT Atlas-based transformation



Summary

- Inrease SPECT in PET efficiency
- Improve spatial resolution
- Better TOF performance in PET
- Better detector performance
- Better collimator design
- Impruve handling organ motion effect